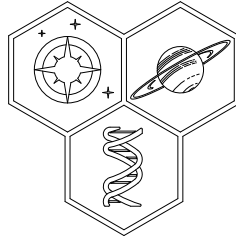


Third Annual NASA Ames Space Science & Astrobiology Jamboree



March 3, 2015



Welcome to the Third Annual Ames Space Sciences and Astrobiology Jamboree!

The Space Science and Astrobiology Division at NASA Ames Research Center consists of over 50 civil servants and more than 110 contractors, co-ops, post-docs and associates. Researchers in the division are pursuing investigations in a variety of fields including exoplanets, planetary science, astrobiology and astrophysics. In addition, division personnel support a wide variety of NASA missions including (but not limited to) Kepler, SOFIA, LADEE, JWST, and New Horizons. With such a wide variety of interesting research going on, distributed among three branches in at least 5 different buildings, it can be difficult to stay abreast of what one's fellow researchers are doing. Our goal in organizing this symposium is to facilitate communication and collaboration among the scientists within the division, and to give center management and other ARC researchers and engineers an opportunity to see what scientific research and science mission work is being done in the division.

We are also continuing the tradition within the Space Science and Astrobiology Division to honor one senior and one early career scientist with the Pollack Lecture and the Early Career Lecture, respectively. With the Pollack Lecture, our intent is to select a senior researcher who has made significant contributions to any area of research within the space sciences, and we are pleased to honor Dr. William Borucki this year. With the Early Career Lecture, our intent is to select a young researcher within the division who, by their published scientific papers, shows great promise for the future in any area of space science research, and we are pleased to honor Dr. Melinda Kahre this year.

We hope you can take advantage of the day to learn something new and meet some new faces!

Sincerely,

Science Organizing Committee

Tim Lee
Mark Fonda
Jessie Dotson
Jeff Hollingsworth
Orlando Santos

Third Annual Space Sciences Jamboree

March 3, 2015

8:00 am	Registration & Poster Setup
8:30 am	Michael Bicay: Welcome & Announcements
8:45 am	<i>Outstanding Early Career Space Scientist Lecture:</i> Melinda Kahre: The Current Mars Climate: Investigating the Coupling Between the Dust and Water Cycles
9:45 am	Natalie Cabrol: Changing Planetary Environments and the Fingerprints of Life: An Overview
10:05 am	Chris McKay: Icebreaker and the search for life on Mars using Antibodies
10:25 am	Poster Session (odd number posters) & Coffee Break
11:10 am	David Summers: Energy Transduction in Vesicles, Driving Enzymatic Reactions with an Abiotic Photosystem
11:30 am	Mark Ditzler: Impact of local environments on the functional potential of RNA
11:50 am	Kathryn Bryson: First Results of the ORGANIC Experiment on EXPOSE-R on the ISS
12:10 pm	Poster Session / Lunch
1:15 pm	Jeff Van Cleve: Congregation of Vapours: Comparing Upper Troposphere / Lower Stratosphere Water Vapor Measurements from Balloons, Satellites and SOFIA
1:35 pm	Ted Roush: Partial Eclipse Observations During the Mohave Volatile Prospector Field Expedition
1:55 pm	Derek Sears: A Meteorite Perspective on Planetary Defense
2:15 pm	Mehmet Alpaslan: The Cosmic Web Unravalled: A study of filamentary structure in the Galaxy and Mass Assembly Survey
2:35 pm	Ryan Hamilton: Observations of the Type Ia Supernova SN2014J with FLITECAM/SOFIA
2:55 pm	Poster Session (even number posters) & Coffee Break
3:15 pm	Joshua Schlieder: The CASTOFFS Survey: New Young M Dwarfs in the Solar Neighborhood
4:00 pm	Rus Belikov: How to Directly Image a Habitable Planet Around Alpha Centauri with a ~ 30-45cm Space Telescope
4:20 pm	<i>Pollack Lecture:</i> Bill Borucki: Kepler Mission: What we learned and how we learned it.
5:20 pm	Remove Posters

ID	Title	Corresponding Author
Astrobiology Posters		
AB.1	Formation of Nucleobases from the UV Irradiation of Pyrimidine in Astrophysical Ice Analogs	Scott Sandford
AB.2	Search for Sugars and Related Compounds in Residues Produced from the UV Irradiation of Astrophysical Ice Analogs	Michel Nuevo
AB.3	Meteoritic Sugar Derivatives: Enantiomer Excesses And Laboratory Attempts At Duplication	George Cooper
AB.4	Searching for the prebiotic origins of citric acid cycle metabolites: a mechanistic investigation based on the abiotic chemistry of pyruvic acid	Andro Rios
AB.5	Upper Atmosphere Detection of Meteoritic Organics by a Mid-Infrared Small Satellite Spectrometer (MIRSSS)	David Summers
AB.6	Ground Control Experiments and Flight Sample Preparation for the International Space Station OREOcube: ORganics Exposure in Orbit Experiment.	Katie Bryson
AB.7	The structure and chemical layering of Proterozoic stromatolites in the Mojave Desert	Chris McKay
AB.8	In vitro evolution of distinct self-cleaving ribozymes from alternate environments	Milena Popovic
Astrophysics Posters		
AP.1	A Kepler Galaxy Survey Establishing the Temporal Baseline for Extragalactic Systems	Michael Fanelli
AP.2	Large Scale Balck Hole-Driven Outflows in Giant Elliptical Galaxies	Pasquale Temi
AP.3	Resolved dust emission analysis in IC1459 and NGC2768.	Alexandre Amblard
AP.4	Big Bursts of Star Formation from LITTLE THINGS1: Starburst Triggers of Six Blue Compact Dwarf Galaxies	Trisha Ashley
AP.5	Star Formation In All the Wrong Places, and Other Astronomical Puzzles, Revealed By the SOFIA Observatory	Pamela Marcum
AP.6	Identifying New Molecules from Comparison of Herschel-HIFI Spectra with ab initio Computational Spectra	Naseem Rangwala
AP.7	Quantitative Calibration of the Interstellar PAH Emission Band Charge Proxy and Deriving Local Physical Conditions	Christiaan Boresma
AP.8	Investigations of Carbonaceous Grain Formation for Circumstellar Studies	Cesar Contreras

AP.9	Chemical Dynamics on the Formation of C ₆ H ₅ ⁺ in an Argon–Acetylene Cold Plasma and Implications for Circumstellar Models	Cesar Contreras
AP.10	Synthesis of Pure and N-substituted Cyclic Hydrocarbons (e.g. Pyrimidine) via Gas–Phase Ion–Molecule Reactions	Partha Bera
Exoplanet Posters		
EP.1	Instrument design to directly image the HZ of Alpha Centauri	Eduardo Bendek
EP.2	A method to directly image exoplanets in multi-star systems such as Alpha–Centauri	Sandrine Thomas
EP.3	Laboratory Demonstration of EXCEDE Polychromatic Contrast in Vacuum	Dan Sirbu
Planetary Atmosphere & Climate Posters		
PA.1	Laboratory Demonstration of EXCEDE Polychromatic Contrast in Vacuum	Xinchaun Huang
PA.2	The THS experiment: simulating Titan's atmospheric chemistry at low temperature (200K)	Ella Sciamma O'Brien
PA.3	Possible formation of organic aerosols in Pluto's atmosphere	Hiroshi Imanaka
PA.4	Xenon Fractionation, Hydrogen Escape, and the Oxidation of the Earth	Kevin Zahnle
PA.5	Northern Late Winter Planetary Waves: MRO/MARCI Observations and Mars Climate Model Simulations	Jeff Hollingsworth
PA.6	Secular Climate Change on Mars: Is it Happening?	Bob Haberle
Planetary Surfaces & Interior Posters		
PS.1	Laboratory Investigations of the Complex Refractory Organic Material Produced from Irradiation of Pluto Ice Analogs	Christopher Materese
PS.2	Authigenic clay mineral formation at Yellowknife Bay provides constraints on Ancient Martian PCO ₂	Thomas Bristow
PS.3	Crater Morphology in the Phoenix Landing Ellipse: Insights into Net Erosion and Ice Table Depth	Eldar Noedobrea
PS.4	Topographic Mapping of Paterae and Layered Plains on Io Using Photoclinometry	Oliver White
PS.5	Phase–Dependence of Physical Parameters of Near Earth Asteroids	Diane Wooden

The Current Mars Climate: Investigating the Coupling Between the Dust and Water Cycles

Melinda A. Kahre

The dust and water cycles are critically important for the current climate of Mars. While it has been known for decades that the radiative effects of dust impact the thermal and dynamical state of the atmosphere, the importance of water ice clouds on the state of Mars' current climate has been recognized more recently. Although dust is present in the Martian atmosphere throughout the year, the level of dustiness varies with season. The atmosphere is generally the dustiest during Northern Hemisphere (NH) fall and winter and the least dusty during NH spring and summer. Broadly, there are two categories of water ice clouds in the Martian atmosphere: the aphelion cloud belt and the polar hood clouds. The aphelion cloud belt is composed of optically thin clouds that form above 10-15 km at low latitudes during NH spring and summer. Polar hood clouds are optically thick and form near the edge of the advancing and receding polar cap in both hemispheres during local fall and winter.

Cloud formation is the key process for the coupling between the dust and water cycles (Figure 1). Dust particles provide the seed nuclei for heterogeneous nucleation of water ice clouds. As ice coats atmospheric dust grains, the newly formed cloud particles exhibit different physical and radiative characteristics. The coupling between the dust and water cycles most likely affects the atmospheric distributions of dust, water vapor and water ice and thus atmospheric heating and cooling and the resulting circulation and dynamics. We are interested in how these couplings affect the current climate of Mars.

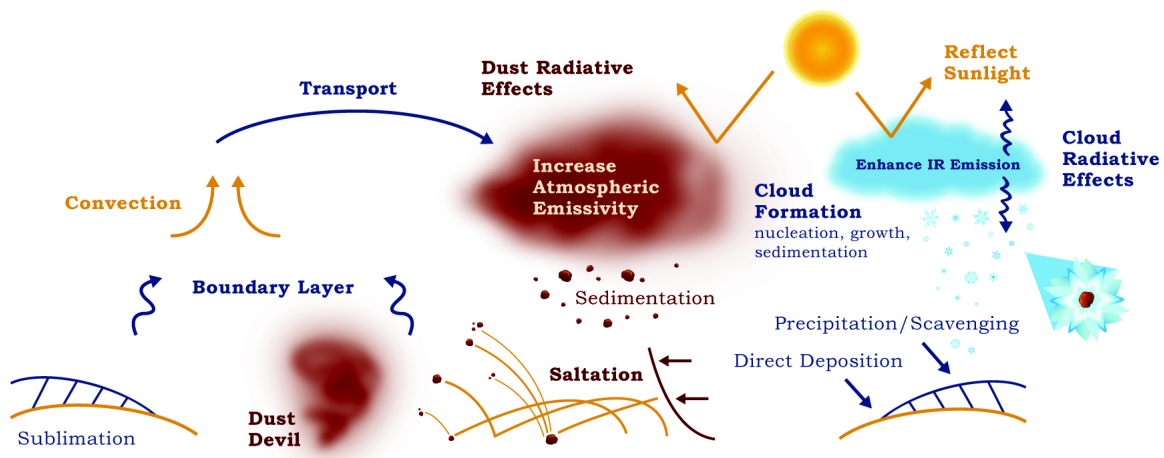


Figure 1: Key processes of Mars' dust and water cycles.

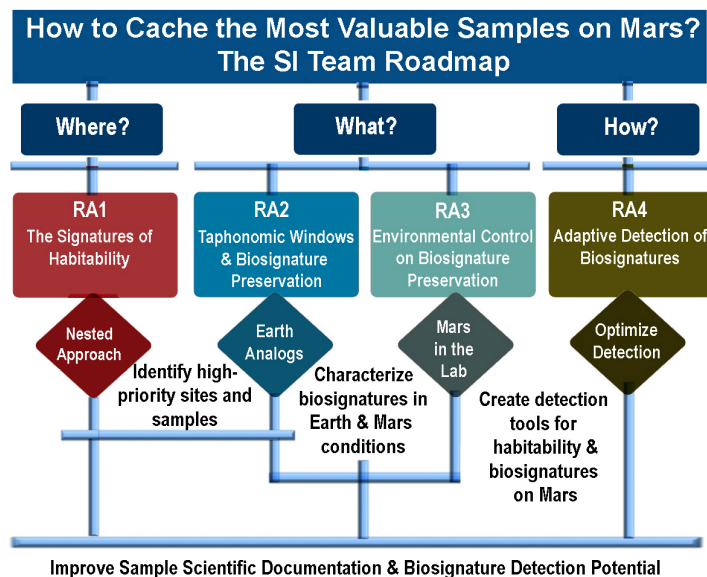
We use the NASA Ames Mars Global Climate Model (GCM) to isolate and investigate the climatic effects of coupling the dust and water cycles. Three main results will be discussed: 1. The radiative effects of polar hood clouds during NH autumn increase the intensity of NH traveling weather systems and the vigor of dust lifting by these systems; 2. A radiative/dynamic feedback between clouds, the mean overturning circulation, and the vertical extent of dust produce a polar warming that is consistent with observations during NH summer, and; 3. Clouds entirely suppress a robustly simulated global dust storm during NH winter.

Changing Planetary Environments and the Fingerprints of Life: An Overview

Authors: Cabrol, N. A.^{1,2}, D. Andersen¹, J. Bishop¹, D. Blake³, A. Brown¹, S. Cady⁴, A. Davila^{1,2}, E. DeVore¹, G. Ertem¹, J. Farmer⁵, U. Feister⁶, E. A. Grin^{1,2}, V. Gulick^{1,3}, D-P. Häder⁷, N. Hinman⁸, R. Leveille⁹, J. Moersch¹⁰, V. Parro¹¹, C. Phillips¹, W. Pollard¹², R. Quinn^{1,3}, P. Sarrazin¹, P. Sobron¹, D. Summers¹, D. Wettergreen¹³, J. Wray¹⁴, K. Zacny¹⁵. First author email: Nathalie.A.Cabrol@nasa.gov. **Affiliations:** **1.** The SETI Institute Carl Sagan Center; **2.** NASA Ames, MS 245-3; **3.** NASA Ames, MS 239-4; **4.** Pacific Northwest National Lab; **5.** Arizona State University School of Earth and Space Exploration; **6.** Lindenberg Meteorological Observatory (Germany) **7.** University of Erlangen (Germany); **8.** University of Montana; **9.** Canadian Space Agency; **10.** University of Tennessee, Knoxville; **11.** Centro de Astrobiología (Madrid, Spain); **12.** McGill University (Canada); **13.** Carnegie Mellon University Robotics Institute; **14.** Georgia Tech.; **15.** Honeybee Robotics.

Science Topic: Astrobiology

Abstract: In the next 5 years, the SETI Institute (SI) NASA Astrobiology Institute (NAI) team will develop a roadmap to biosignature exploration in support of NASA's decadal plan for the search for life on Mars. The earliest opportunity for NASA to search for traces of life on early Mars will be the Mars 2020 mission, when a Curiosity-class rover is expected to explore ancient habitable environments and cache a limited number of samples. Caching samples entails high-cost and high-risk. Therefore, the single most compelling question to ask in support of such a mission is "*How do we identify and cache the most valuable samples?*". The SI team research program includes four primary research areas to study the essential components of this question. Within them, focus areas regroup investigations that synergistically tackle key aspects of early Mars habitability, taphonomic windows and biosignature potential, their preservation potential, and their detectability. Research is performed through an integrated exploration of ever-increasing



taphonomic windows, potential for biosignatures and their preservation potential. Technologically, the research program will advance the understanding of the performance of instruments providing data on threshold and baseline measurements recommended by the Mars 2020 Science Definition Team to satisfy the scientific documentation of high-priority samples, and will evaluate their individual and combined diagnostic power on key Mars analog materials. Methodologically, the SI team will synergistically investigate environments and biogeomaterials at ever-increasing resolution to support, ground-truth, and validate results every step of the way.

While this research will directly support the Mars 2020 mission, its overarching goal is much broader and intended to develop a roadmap to biosignature exploration for Mars. This roadmap may be revised in the future in response to research and discoveries, but it aims to produce the fundamental guiding principles of an exploration strategy that, ultimately, will help NASA return the most valuable martian samples to Earth.

Icebreaker and the search for life on Mars using Antibodies. Y. Blanco¹, G. de Diego-Castilla¹, A. Davila², I. Gallardo-Carreño¹, C. Stoker², C. McKay², and V. Parro¹. ¹Centro de Astrobiología (INTA-CSIC), Carretera de Ajalvir km4, Torrejón de Ardoz, Madrid, Spain, parrogy@cab.inta-csic.es, ²NASA-Ames Research Center, Moffet Field, CA, USA. chris.mckay@nasa.gov

Introduction: The proposed Icebreaker mission to Mars seeks to find organic biosignatures in ice-rich soils of the northern plains, where transient habitable conditions might have occurred within the last 1 Myr, during high obliquity cycles (McKay et al. 2013). *Icebreaker will be the first mission since Viking to search for evidence of extant life on Mars.* Icebreaker will search for specific biomarkers under the assumption that life on both planets shared a similar or possibly common origin, and certain primeval and conserved biomolecules in Earth biochemistry are also part of a martian biochemistry.

On the possible nature of martian life: It is commonly assumed that life originated on Earth as soon as conditions allowed. Decades ago, it was also commonly assumed that if life ever evolved on Mars, it originated independently—a second genesis. A third possible scenario is that life originated only once, and was transferred between both planets. Probabilistically, the latter scenario is considered the most likely.

Selection of target biomarkers: A common origin of life on Earth and Mars implies that life on both planets would likely share a similar subset of complex biomolecules (Parnell et al., 2007; Davila and McKay, 2014). Indeed, particular membrane components, energy production and storage mechanisms, and certain biomolecules such as RNA and DNA appear to be *ancient* and evolutionarily *conserved*—they can be found almost unchanged among practically all prokaryotes. The reason these biomolecules are ancient and

However, because of the high cosmic ray dose on Mars, organic biosignatures generated during such recent spurs of biological activity could still undergo severe radiolytic degradation, leading to a partial or complete loss of biological information (Dartnell et al. 2007). This poses constraints on the approaches used to search for evidence of life.

The Signs of Life Detector (SOLID) Instrument, a component of the Icebreaker mission science payload, has been developed to search for a specific suit of organic biosignatures using Fluorescence Sandwich Immunoassay (FSI). In a FSI, purposely selected Antibodies (Abs) recognize and bind to desired biomarkers or Antigens (Ag) with high specificity Parro et al. (2011). Abs recognize and bind to a small region of the Ag, called the epitope. In principle, because epitopes are comparatively small, they are more likely to be preserved than entire organic biosignatures, and yet they retain discriminatory molecular information. However, few studies exist on the effects of high ener-

gy radiation on epitopes during time scales equivalent to recent obliquity cycles on Mars.

We tested whether biological polymers such as proteins and peptides can be still detected by an immunoassay after exposing to 1 to 10 equivalent My martian radiation doses. We consider the radiation measurements taken by the MSL mission as the most accurate and realistic on the surface of Mars, being 0.21 mGy/day.

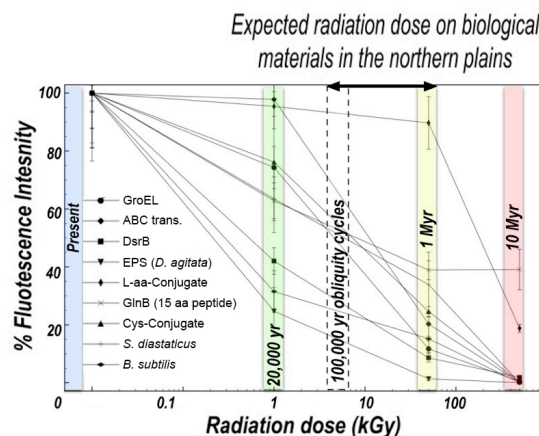


Figure 1. Effect of radiation dose on the immunological detection of biomolecules. Plotting the loss of fluorescence as a function of the radiation dose compare to the blank (no radiation, 100% intensity).

The fluorescent signal from each tested organic biosignature was observed to decrease with radiation dose, indicating damage to the epitope structure. The extent of the damage seemed to depend on epitope complexity, with smaller and simpler ones being less affected than larger ones. However, in most cases 10 to 50% of the original fluorescence signal was retained after 50 kGy (equivalent to 1My exposure), and 1 to 20% of the original fluorescence (depending the type of molecule) was retained after 500 kGy (i.e. 10 My exposure). This implies that a significant fraction of Abs could still bind to intact or partially damaged epitopes (Fig 1.).

No additional effects were observed in the presence of 20 mM perchlorate (10 times higher than that found in Phoenix landing site). More studies are needed with more simple biomolecules such as protein or peptides to fully understand the effects of radiation.

McKay et al., (2013) *Astrobiology*, 13, 334-353.

Dartnell et al., (2007) *GRL* 34, L02207.

Davila & McKay (2014) *Astrobiology*, 14, 534-540.

Parnell et al. (2007) *Astrobiology*, 7, 578-604.

Parro et al., (2011) *Astrobiology* 11, 15-28.

Title: Energy Transduction in Vesicles, Driving Enzymatic Reactions with an Abiotic Photosystem.

Authors: D. P. Summers, Tsege Embaye, and David Rodoni

Science Topic: Topic Astrobiology

Introduction: A number of theories on the origin and early evolution of life have focused on the role of lipid bilayer membrane structures often called vesicle. These vesicles are similar to modern cellular membranes, and have been postulated to have been abiotically formed and spontaneously assemble on the prebiotic Earth. The origin of the use of photochemical energy to drive metabolism (ie. energy transduction) is also one of the central issues in our attempts to understand the origin and evolution of life. When did energy transduction and photosynthesis begin? What was the original system for capturing photochemical energy? How simple can such a system be?

It has been postulated that vesicle structures developed the ability to capture and transduce light, providing energy for reactions. It has been shown that pH gradients can be photochemically created, but it has been found difficult to couple these to drive chemical reactions. Minerals can introduce a number of properties to a vesicle system. The incorporation of clay particles into vesicles can provide catalytic activity that mediates both vesicle assembly and RNA oligomerization.

It has been shown that mineral semiconducting particles can act as photocatalysts, driving electrochemical reactions. We have shown that titanium dioxide particles will be encapsulated as vesicles form, or reform after dehydration/rehydration cycles, without interference in either lipid or semiconductor properties. They can be concentrated in vesicles by dehydrate/rehydrate cycles and that they retain the ability to drive photoelectrochemical reactions. The encapsulation of these particles can provide a simple energy transduction system for vesicles that could have formed at almost any stage of the origin of life.

Results: Quinones are important redox carrier in modern biochemistry. Our work has shown that quinones can be used as a redox carriers in our non-biological system and can drive the reduction of biochemical species such NAD⁺ to NADH. We have also shown that they driven enzymatic reactions directly, such as the reduction of nitrate to nitrite.

This system demonstrates a simple energy source inside vesicles/protocells suitable either for simple prebiotic systems and/or for more complex “protobiochemical” systems. It could act as a precursor to metabolic systems and provide a model of how metabolism could have developed prebiotically in a vesicle based “protocell origin of life”. This would demonstrate a possible path for the origin and early evolution of photosynthesis.

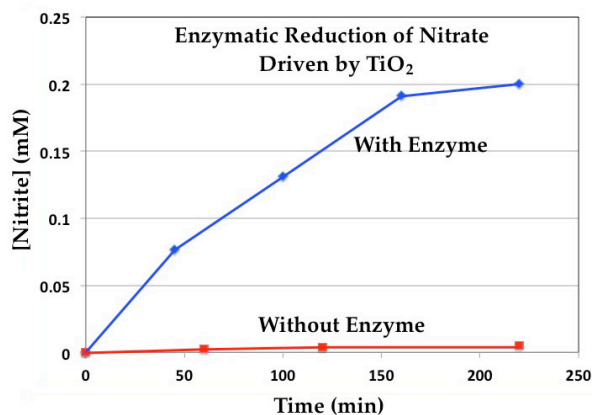


Figure 3. Nitrite formation vs. time during the irradiation of 1% TiO₂, 0.8 mM Bis(ethanolamino)benzoquinone, 0.25 units/ml nitrate reductase, 1% MeOH in 0.1 phosphate buffer, pH 7.5.

Impact of local environments on the functional potential of RNA

Mark Ditzler, Milena Popović, James Stephenson, Palmer Fliss
Astrobiology

Ribonucleic acid (RNA) is an essential biopolymer in modern biology and it figures prominently in many scenarios for the origin and early evolution of life. RNA molecules may have played a larger role in ancient biology than they do now, acting both as the primary biocatalysts and as the sole repository of genetic information. Several features of modern biochemistry provide strong support for RNA's dominant role in early life, such as the central role of ribosomal RNA in protein synthesis, the pervasive involvement of nucleotides in enzymatic cofactors, the existence of natural RNAs that bind these cofactors, the existence of multiple catalytic RNAs, and a conserved biosynthetic pathway in which deoxynucleotides are produced from ribonucleotides. Additionally, RNA's potential to serve as the primary biocatalyst is supported by *in vitro* evolution experiments that demonstrate RNA's ability to catalyze diverse chemical reactions.

Discovery of functional RNAs by *in vitro* evolution is used to develop and constrain the role of RNA in origin of life theories. *In vitro* evolution examines sequence space both locally and globally to gain insight into what RNA can do, how common functional RNAs are in sequence space, how complex functional RNAs need to be, and how RNA can evolve new functions. RNA function is known to be sensitive to several environmental factors such as, pH, temperature, ionic strength, counter ion identity, and the presence of mineral surfaces through both experiment and simulation. The extent to which RNA could have supported specific functions in the earliest forms of life is therefore dependent on the environments in which life emerged. However, the range of conditions used for *in vitro* evolution experiments is narrow relative to both the range proposed for the origin of life and the conditions under which RNAs is known to function in extant biology. Therefore, understanding RNA's potential to support specific functions in both ancient and modern biology requires a broader exploration of parameter space using *in vitro* evolution.

To better understand the impact of the local environment on the functional capacity and evolution of RNA, we have evolved several populations of catalytic RNAs. These RNA populations were evolved in a variety of different environments *in vitro*. RNA populations were evolved in the presence of either Mg^{2+} or Fe^{2+} under anoxic conditions and in the presence or absence of clay mineral surfaces. Evaluating these populations allows us to understand the impact of the local environment on RNA's functional potential, explore what roles RNA could have played in the origin of life, and identify conditions favorable to RNA catalysis.

First Results of the ORGANIC Experiment on EXPOSE-R on the ISS. Kathryn Bryson (BAERI/SSA), Farid Salama (SSA), Andreas Elsaesser (*Leiden Institute of Chemistry*), Zan Peeters (*Carnegie Institute of Washington*), Antonio Ricco (RD), Bernard Foing (ESA), Yulia Goreva (*Smithsonian Institution*)

Science Topic: Astrophysics

Introduction: Aromatic networks are among the most abundant organic material in space. PAHs and fullerenes have been identified in meteorites and are thought to be among the carriers for numerous astronomical absorption and emission features. Thin films of selected PAHs and fullerenes have been subjected to the low Earth orbit environment as part of the ORGANIC experiment on the multi-user facility EXPOSE-R onboard the International Space Station. The ORGANIC experiment monitored the chemical evolution, survival, destruction, and chemical modification of the samples in space environment. The results have been discussed in a recently published study^[1].

The ORGANIC Experiment: EXPOSE-R with its experiment inserts was mounted on the outside of the ISS from 10 March 2009 to 21 January 2011. The samples were returned to Earth and inspected in spring 2011. The 682-day period outside the ISS provided continuous exposure to the cosmic-, solar-, and trapped-particle radiation background, and an irradiation dose of the order of 14000 MJ/m² over 2900h of unshadowed solar illumination. All trays carry both exposed and dark samples shielded from the UV photons, enabling discrimination between the effects of exposure to solar photons and cosmic rays.

The samples were analyzed before exposure to the space environment with UV-VIS spectroscopy. Ground truth monitoring of additional sample carriers was performed through UV-VIS spectroscopy at regular intervals at NASA ARC. During the exposure on the ISS, two control sample carriers were exposed with a slight time shift in a planetary simulation chamber at the Microgravity User Support Center (MUSC) at DLR. Vacuum, UV radiation, and temperature fluctuations were simulated according to the telemetry data measured during flight. Analytical studies of the returned samples and ground simulation samples included spectral measurements from the vacuum ultraviolet (VUV) to the infrared (IR) range and time-of-flight secondary ion mass spectrometry.

Limited spectral changes were observed in most cases pointing to the stability of PAHs and fullerenes under space exposure conditions. The results of these experiments confirm the known trend in the stability of PAH species according to molecular structure: compact PAHs (Fig 1.) are more stable than non-compact PAHs (Fig 2.), which are themselves more stable than PAHs containing heteroatoms, the last category being the most prone to degradation in the space environment.

We estimate a depletion rate of the order of $85 \pm 5\%$ over the 17 equivalent weeks of continuous unshadowed solar exposure in the most extreme case tetracene (smallest, non-compact PAH sample). The insignificant spectral changes (below 10%) measured for solid films of large or compact PAHs and fullerenes indicate a high stability under the range of space exposure conditions investigated on EXPOSE-R.

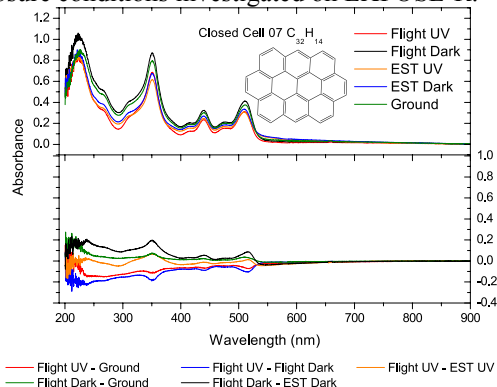


Fig. 1. UV-Vis spectra of ovalene thin films deposited on MgF₂ disks integrated into sample cells (top panel) and calculated residual spectra (bottom panel). The residual spectra show minor depletion (less than 10 %) of ovalene thin films in the UV-exposed flight cells. From Reference [1]

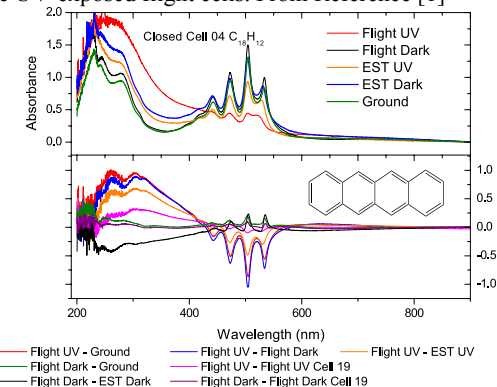


Fig. 2. UV-Vis spectra of tetracene films deposited on MgF₂ disks (top panels) and calculated residual spectra (bottom panels). The samples exposed to space conditions (Flight UV) show strong changes in absorbance due to UV photolysis leading to absorbance spectral residuals of the order of 10 – 20% for bands in the 400 – 600 nm range^[1].

References: [1] Bryson et al. International Journal of Astrobiology, 2014

Acknowledgements: Support by NASA SMD APRA and NAI programs and ESA's HSM program is acknowledged. The authors acknowledge the outstanding technical support provided by R. Walker and the contributions of P. Ehrenfreund's (PI of ORGANIC), P. Monaghan, D. Wills, E. Jessberger, A. Bischoff, M. Breitfellner, F. Robert, Søren Hoffmann and Nikola Jones.

Oral Presentation: 1:15 pm

Title: "Congregation of Vapours: Comparing Upper Troposphere/Lower Stratosphere Water Vapor Measurements from Balloons, Satellites, and SOFIA"

Authors: Jeffrey Van Cleve & Allan Meyer (USRA-SOFIA), Tom Roellig (NASA-Ames), Lunming Yuen (Wyle)

Science Topics: Planetary Atmospheres & Climate



Abstract: The density of water vapor (WV) in Upper Troposphere/Lower Stratosphere (UTLS) is of great importance to weather, climate, and calibration of SOFIA data at water-sensitive wavelengths, in particular in the strategic 28-300 micron range. Yet WV in the UTLS, here defined as the 300 to 100 mbar pressure level (30 to 53 kft in the Standard Atmosphere) is in some sense *terra incognita*. Above 30 kft, results from sensors like the GOES Sounder (a 19-channel discrete-filter mid-IR radiometer) may be heavily contaminated by WV and weather in the middle stratosphere, since all the weighting functions for sensor bands peak at or below 30 kft (Meyer, 2013). Below 53 kft, comparisons of measurements between different platforms becomes difficult because water vapor is much more variable spatially and temporally between 30 and 53 kft than it is above 53 kft (Hurst, 2013), which is indeed the reason SOFIA has an on-board WV monitor (WVM) to calibrate its astronomical instruments. In-situ NOAA frost point hygrometer (FPH) data, collected monthly over Boulder, offers a way to assess the strengths and weaknesses of satellite data and develop a calibration plan for the SOFIA WVM. In this talk, we report work in progress on tools for extracting meteorological data and analyses along the SOFIA flight path for comparison to WVM measurements. We discuss some possibilities for synoptic observations with the SOFIA WVM, in addition to GOES: overflight of a special night FPH launch, overflight of the Table Mountain lidar on Palmdale departure/arrival, and spatiotemporal coincidence with AURA-MLS ground tracks. We conclude with some speculation about how understanding these comparisons may allow a well-calibrated SOFIA WVM to make a serendipitous contribution to climate science as it goes about its normal operations.

Partial Eclipse Observations During the Mojave Volatile Prospector Field Expedition. T. L. Roush¹, A. Colaprete¹, J. Heldmann¹, D. S. S. Lim², A. Cook³, R. Elphic¹, M. Deans¹, L. Fluckiger¹, E. Fritzler³, David Hunt¹, ¹NASA Ames Research Center, Moffett Field, CA 94035-1000, ²BAER, Inst., 625 2nd St., Petaluma, CA, 94952, ³Millennium Eng. & Integration Co., 350 N. Akron Rd., Moffett Field, CA 94035:
Topic: Planetary Surfaces

Introduction: During 21-26 October 2014 the Mojave Volatile Prospector (MVP) field expedition operated the NASA Ames Krex2 rover in west of Baker, California (Fig. 1, bottom). The primary goals of MVP were to characterize the surface and sub-surface soil moisture properties within alluvial fans, and as provide mission operations simulations of the Resource Prospector (RP) mission to a Lunar pole. The partial solar eclipse of 23 October (begin/end ~21:09/~23:40 UT, with maximum obscuration, 36%, 22:29 UT) provided an opportunity during MVP operations to address serendipitous science. The instrument used to monitor the eclipse was the engineering development unit of the Near-Infrared Volatile Spectrometer System (NIRVSS) near-infrared spectrometer. Data are obtained approximately every 8 seconds. The NIRVSS stares in the opposite direction as the front Krex2.

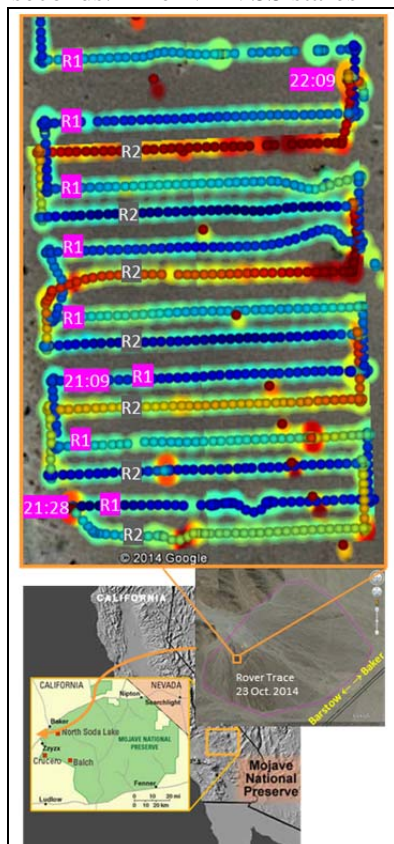


Figure 1. MVP field expedition location (bottom, overview maps from National Park Service) and the rover tracks during the eclipse observations on 23 October 2014 (top). R1 is the proximal to distal raster and R2 is the opposite pattern. Times germane to the eclipse are highlighted.

Field Observations: The primary objective of MVP on 23 October was to characterize a specific alluvial fan, and to confirm repeatability of spectral observations. An approximate East-West raster scan was designed and implemented from the proximal to distal portion of the fan (R1, Fig. 1, top) and another scan was performed in the reverse direction with an offset (R2, Fig. 1, top). Initial eclipse observations oriented the rover facing away from the sun to allow NIRVSS to more directly view the reflected sunlight. This careful positioning was deemed too time consuming to achieve the primary science objective. During both traverses the Krex2 was frequently rotated 360° with a halt at every 60°. In lieu of dedicated eclipse observations, NIRVSS operated continuously during these spins. These dynamic observations are obtained as the position of the rover, surface, sun, and any clouds change during the traverses. Disentangling the influence of each is challenging. Fortunately NIRVSS data was obtained at similar times on other days and permit comparison to the eclipse observations.

Analyses: We initially restrict analyses to observations obtained at >170° solar phase angle. The proxy for brightness is the mean short-wavelength radiance. As the solar altitude decreases with time potentially more sunlight comes under Krex2 so we applied a correction and scaled the data to the initial radiance on each day. The trends seen in the data are generally described by this correction, but some scatter remains and we speculate this may be due to surface reflectance differences, and/or atmospheric influence.

Discussion: We see a slight decrease in the mean radiance associated with the maximum of the partial solar eclipse. However, it is not currently possible to conclude that this is due solely to the eclipse event. Atmospheric influences would not be an issue on the lunar surface, the influence of surface reflectance and textural differences would remain. The ideal acquisition of data during the partial solar eclipse, would have been to remain static and only rotate to track solar azimuth angle. However, during a lunar mission such a dramatic departure from the primary science goals may not be scientifically acceptable.

A METEORITE PERSPECTIVE ON PLANETARY DEFENSE. D. W.G. Sears^{1,2}, Timothy J. Lee¹, Jesse Dotson¹, Megan Syal³, Damian C Swift³. ¹NASA Ames Research Center (ARC), Moffett Field, CA, U.S.A., ²BAER Institute, 625 2nd St., Suite 209, Petaluma, CA 94952, USA ³Lawrence Livermore National Laboratory (LLNL), 7000 East Avenue, Livermore, CA 94550.

Introduction: Following the fall of the Chelyabinsk meteorite [1,2], and programs to detect hazardous asteroids and mitigate their threat to Earth [3,4], we have established a team and are developing laboratories at the ARC and LLNL designed to provide the information needed to understand (1) the physics of meteorite fall and (2) the details of asteroid surfaces needed to develop deflection techniques. Here we review our thoughts on what can be learned about planetary defense from meteorites and meteorite falls.

I. The Mechanics of Meteorite Falls.

Observed Falls: While subjective in nature, eye witness observations of meteorite falls have the potential to provide unique insights into the physics of entry into the Earth’s atmosphere (Fig. 1). A limited but suggestive study [5] demonstrates the potential of reviewing large numbers of literature fall descriptions (Table 1). Witnesses can also indicate the amount of dust associated with a fall which, in turn, provides information on the amount of fragmentation and ablation (Fig. 2, [6]).

Table. 1. Fall descriptions of 20 meteorites in the Meteoritical Bulletin (Apr 1960 – Nov 1970) [5].

Feature	No.	%
Explosion	17	85
Rumbling	7	35
Whistling	9	45
Impact sounds	4	20
Light	11	55
Flares	2	10
Dust trail	6	30



Fig. 1. The Sutter’s Mill meteorite, like Chelyabinsk, is an example of a recent meteorite fall that was well observed and even photographed so its fall behavior is well understood [7].

Light Curves: Until the early 1990s it took expensive networks to obtain light curves for fireballs (Fig. 3). Since the development of private video equipment, nearly 20 meteorite falls have been recorded and light curves obtained [e.g. 8]. Light curves

enable quantitative information on the beginning and end of luminous flight, the rate of energy loss, the dynamic and photometric mass, major break-up events, and velocity as a function of time. More importantly, the light curve is quantitative data that can be used to test numerical models.



Fig. 2. Chelyabinsk is an example of a meteorite that produced considerable dust reflecting its high rate of fragmentation and ablation.

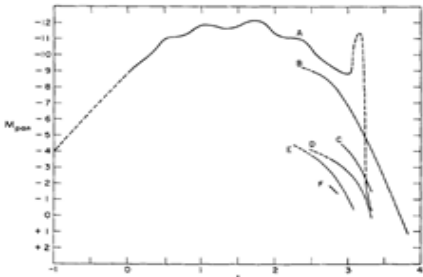


Fig. 3. Light curve for the Innisfree meteorite [9]. The slow rise and sudden drop, oscillations, and flares, provide information that can be numerically modeled.

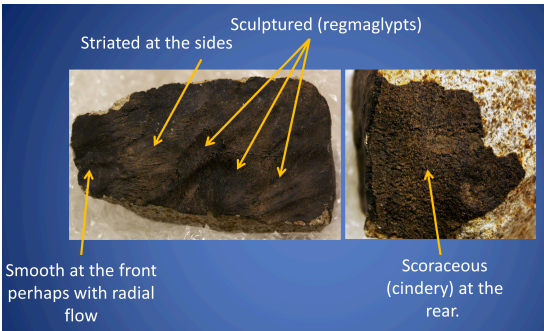


Fig. 4. The fusion crust enables insights into the later stages of atmospheric flight, including air flow, thermal gradients, and ablation rates [11].

Fusion Crust and Shape: The fusion crust is an eye witness of the later stages of flight (Fig. 4). From its surface texture, details of airflow around the meteorite can be determined, and from the petrography of the fusion crust and underlying layers, thermal gradients and ablation rates can be determined [5,10,11].

From the shape and coverage by fusion crust, the degree of orientation, can be determined.

Table 2. Craters with meteorites [12]

Crater	Meteorite		
Wabar	Iron (IIIAB)	Macha	Iron (Iron)
Kaalijarvi	Iron (IAB)	Monturaqui	Iron (IAB)
Henbury	Iron (IIIAB)	Wolf Creek	Iron (IIIAB)
Odessa	Iron (IIIAB)	Meteor	Iron (IAB)
Boxhole	Iron (IIIAB)	Rio Cuarto	H Chondrite

Meteorite Fragments from Craters: Of the 10 meteorite impact craters from which meteorites have been recovered, nine were iron meteorites (Table 2). The exception is the largest crater which was produced by an H chondrite [12]. Here we have a unique opportunity to test numerical models because we have two pieces of critical data, the crater and the meteorite.

II. Details Fall and Asteroid Surfaces

Meteorite characterization not only aids in modeling atmospheric behavior, it also has the potential to provide insights into the asteroid surfaces.

Laboratory Studies of Meteorites: Of course, since we have the meteorites in our laboratories any number of relevant measurements can be made.

Table 3. Mass loss for meteorites during atmospheric passage estimated from cosmogenic isotopes [5].

Meteorite	(%)	Meteorite	(%)
Abee	37, 51	Ochansk	0,0,0
Akaba	99	Parnallee	95, 99
Beenham	78	Ramsdorf	99, 99
Colby, Wisc	24	Saline	92.2
Dimmitt	96.5	St. Germain	87
Finney	95	St. Severin	0, 32
Kiel	80	Texline	95.8
Ladder Creek	94.2	Tieschitz	86
Leedey	87.5	Tynes Island	96.7
Maziba	95	Utzenstorf	93.2
Mezo Madaras	98.4, 94.2	Walters	97.2, 95.3
Mocs	40, 70, 99.7	Pulsora	99, 99
Narellan	96	Ramsdorf	99
Ness City	98.3	Saline	92.2
Norton County	56	Weston	75, 81

Chemical properties. Samples in the laboratory can be subjected to a vast array of analyses, starting with those required for classification.

Physical Properties. Essential properties such as density, porosity, thermal conductivity, heat capacity, acoustic properties, and tensile, compressive, and deformation strength, albedo and spectra, can be measured accurately [13-15].

Preatmospheric Size. Studies of cosmogenic isotopes can be used to calculate preatmospheric mass. For example, Table 3 suggests that while most meteorites suffer >98% mass loss in coming through the atmosphere, 25% show relatively little mass loss.

Internal Structure. Meteorites of the same chemical class can have very different internal properties that can greatly influence atmospheric behavior (Fig. 5).



Fig. 5. Internal structure critically affects atmospheric behavior. Above are chemically similar meteorites, one was made extremely weak (Chelyabinsk, left) and one was made extremely tough (Novato, right) by impact events in space.

III. Asteroid surfaces

Regolith Breccias: The gas-rich regolith breccias (with characteristic light-dark texture) are samples from the very surface of their parent asteroids and provide unique information on the surface of asteroids (Fig. 6, [16]).



Fig. 6. The Fayetteville gas-rich regolith breccia.

Conclusion: Meteorite studies constitute an integral part of the Nation's planetary defense efforts alongside NEA characterization, numerical studies of reentry, risk analysis, and deflection techniques.

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Title: The Cosmic Web Unravelling: A study of filamentary structure in the Galaxy and Mass Assembly survey

Authors: Mehmet Alpaslan, Pamela Marcum, and the GAMA collaboration

Science topic: Astrophysics

Abstract: I have investigated the properties of the large scale structure of the nearby Universe using data from the Galaxy and Mass Assembly survey (GAMA).

I used a volume limited sample of GAMA groups and galaxies to generate the large scale structure catalogue. This was done with an adapted minimal spanning tree algorithm, which identifies and classifies structures, detecting 643 filaments that measure up to $200 \text{ h}^{-1} \text{ Mpc}$, each containing 8 groups on average. A secondary population of smaller coherent structures, dubbed 'tendrils,' that link filaments together or penetrate into voids are also detected. On average, tendrils measure around $10 \text{ h}^{-1} \text{ Mpc}$ and contain 6 galaxies. The so-called line correlation function is used to prove that tendrils are real structures rather than accidental alignments. A population of isolated void galaxies are also identified. The properties of filaments and tendrils in observed and mock GAMA galaxy catalogues agree well.

I go on to show that voids from other surveys that overlap with GAMA regions contain a large number of galaxies, primarily belonging to tendrils. This implies that void sizes are strongly dependent on the number density and sensitivity limits of the galaxies observed by a survey.

Finally, I examine the properties of a mass controlled sample galaxies in different environments. While mass normalised galaxies in voids show subtly higher UV and IR emission, they are no more likely to be blue, faint, or disc-like than their counterparts in filaments. Extending my analysis to groups and pairs, I fail to see a strong dependence of halo mass on Sersic index and galaxy luminosity, but do find that it correlates very strongly with colour. Repeating this analysis without mass control introduces and amplifies trends in the properties of galaxies in pairs, groups, and large scale structure, indicating that stellar mass is the most important predictor of galaxy properties followed by morphological type, halo mass, pair rank, local density and finally large scale structure.

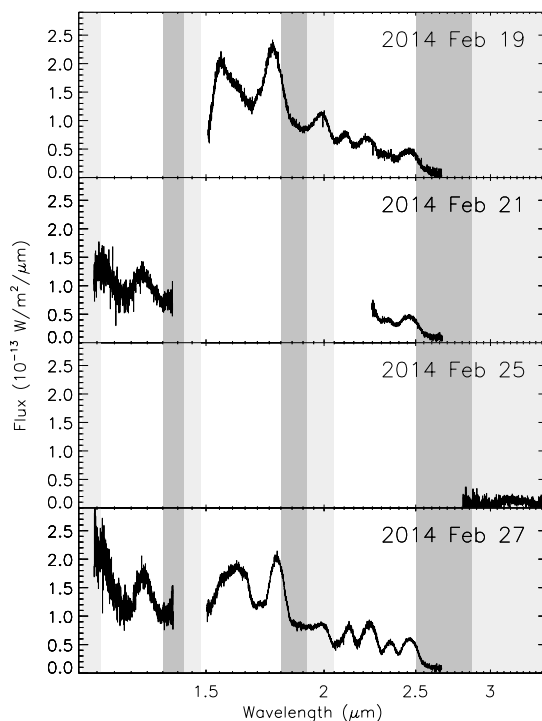
Observations of the Type Ia Supernova SN2014J with FLITECAM/SOFIA

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SOFIA Science Center, NASA Ames Research Center

Astrophysics

We present near-infrared (NIR) spectra of the normal Type Ia supernova (SN Ia) SN2014J obtained with FLITECAM aboard SOFIA. Spectra were obtained 17 – 25 days after maximum B light, covering wavelengths between 1.1 and 3.4 μm . Our 2.8 – 3.4 μm data represent one of the first $\sim 3 \mu\text{m}$ spectra of a SN Ia ever published. The first and final sets of spectra, obtained on 2014 Feb. 19 and 2014 Feb. 27 respectively, span the entire 1.5 – 2.7 μm range. The spectra are characterized by a wealth of strong emission features, with the peak near 1.77 μm showing a full width at half maximum of $\sim 12,000 \text{ km s}^{-1}$. This feature is seen to decrease in width and shift by 0.02 μm between the first and last sets. We compare the observations to the recent non-LTE delayed detonation models of Dessart et al. (2014) and find that the models agree with the spectra



remarkably well in the 1.5 – 2.7 μm wavelength range. Based on this comparison we identify the $\sim 1.77 \mu\text{m}$ emission peak as a blend of permitted lines of Co II, with the observed shift resulting from a change of contributions from the various components. Identifications of the prominent lines in the observed spectra suggest that the NIR spectra of normal SNe Ia at this stage of their evolution are dominated by emission lines at the systemic radial velocities, not highly blue-shifted absorption features as has been claimed in the past for other SNe Ia. Although the models match the observed *H* and *K* band spectra fairly well, they are not as successful at reproducing the spectra in the *J* band or between 2.8 μm and 3.4 μm . Additionally, an emission feature at $\sim 2 \mu\text{m}$ due to [Co III] can be clearly seen on Feb. 27, while the models predict that it should have faded considerably by this time. These observations also demonstrate the promise of SOFIA for future SN observations, by allowing access to wavelength regions inaccessible from the ground, and serve to draw attention to the usefulness of the regions between the standard ground-based near-infrared passbands for constraining SN models.

The *CASTOFFS* Survey: New Young M Dwarfs in the Solar Neighborhood

The census of young stars near the Sun is incomplete, particularly at low-masses. Many constituents of the known sample are members of nearby, young moving groups (NYMGs); loose associations of coeval stars with common Galactic kinematics. By mining astrometric and photometric catalogs, new candidates of the young, low-mass star population can be found via their association with NYMGs. We have therefore developed the **Cool Astrometrically Selected Targets Optimal For Follow-up Spectroscopy** (*CASTOFFS*) survey to identify and characterize previously unrecognized young, low-mass stars. We combine astrometry, photometry, and activity to identify candidates and use dedicated spectroscopic follow-up to verify their youth and group kinematics. We are now 2.5 years into *CASTOFFS* and present results from two follow-up campaigns.

We have pursued high-resolution optical spectra of bright ($V \leq 14$) *CASTOFFS* candidates using FEROS; the fiber-fed, optical, Echelle spectrograph on the 2.2m MPG telescope at La Silla observatory. We observed more than 120 stars with FEROS and used the spectra to measure their radial and rotational velocities, estimate spectral types, and investigate spectroscopic features indicative of youth (Fig. 1). These analyses reveal many high probability members of NYMGs, young field stars, and new wide, visual, and spectroscopic binaries. We also have an ongoing follow-up program using the SpeX medium resolution spectrograph at the 3.0m NASA Infrared Telescope Facility. SpeX is ideal for the fainter ($V > 14$) *CASTOFFS* candidates inaccessible using FEROS. The 0.7 - 2.5 μm coverage of SpeX provides access to multiple atomic and molecular features for spectral typing, age analyses, and radial velocity measurements with $\sim 5 \text{ km s}^{-1}$ precision (Fig. 1).

The new, young M dwarfs identified in the *CASTOFFS* survey are key exoplanet imaging targets for current and future facilities. Their proximity, age, and intrinsically low-luminosities provide optimal contrasts for directly observing young, jovian planets. These stars are of particular interest for exoplanet imaging with the James Webb Space Telescope.

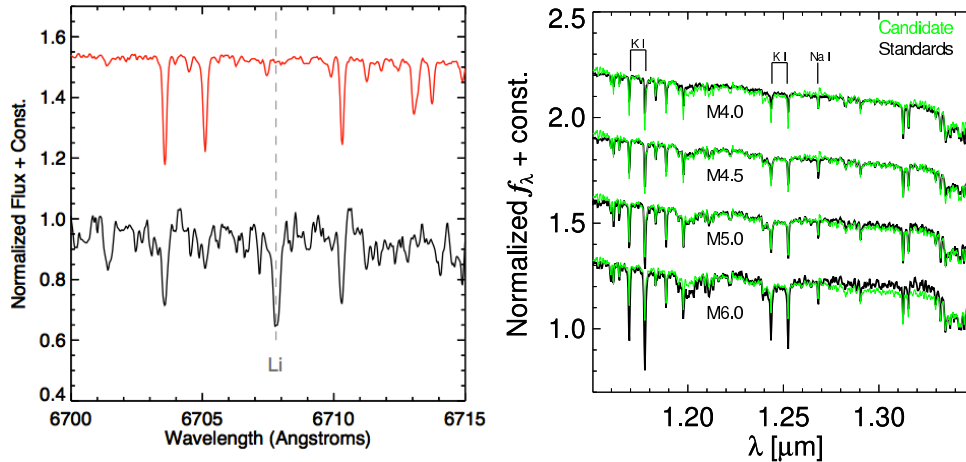


Figure 1: (Left) FEROS spectrum in the region around the Li 6708 Å line of a *CASTOFFS* candidate (black) compared to a radial velocity standard (red) with similar spectral type. Li in the spectrum of the candidate is indicative of a young age. (Right) SpeX *J*-band spectrum of a candidate young M dwarf (green) compared to field age spectral standards (black). Atomic lines sensitive to surface gravity (labeled) can be used as a coarse indicator of the star's age.

How to Directly Image a Habitable Planet Around Alpha Centauri with a ~30-45cm Space Telescope

Ruslan Belikov, Eduardo Bendek, Sandrine Thomas, Jared Males, Ty Robinson, Billy Quarles
and the ACESat team

Science topic: Exoplanets

In 1990, at the request of Carl Sagan, Voyager 1 turned and took a picture of Earth from a distance of 6 billion kilometers. This produced the famous “pale blue dot” image of our planet (see Figure 1). Several mission concepts are being studied to obtain similar images of Earth-like exoplanets (exo-Earths) around other stars.



Figure 1. The original “pale blue dot image” taken by Voyager 1 in 1990.

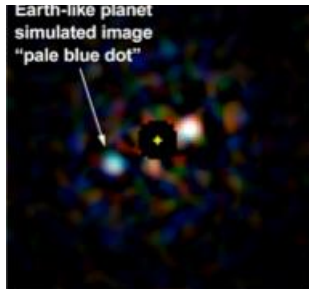


Figure 2. Simulated image of another “pale blue dot”: a possible Earth-like planet around Alpha Centauri A. (Venus- and Mars-like planets are also shown.)

Direct imaging enables spectroscopic detection of biomarkers such as atmospheric oxygen and methane, which would be highly suggestive of extraterrestrial life. It is commonly thought that directly imaging a potentially habitable exoplanet requires telescopes with apertures of at least 1 meter, costing at least \$1B, and launching no earlier than the 2020s.

A notable exception to this is Alpha Centauri (A and B), which is an extreme and fortuitous outlier among FGKM stars in terms of apparent habitable zone size. Specifically, Alpha Centauri habitable zones span about 0.5-1” in stellocentric angle, ~3x wider than around any other FGKM star. This enables a ~30-45cm visible light space telescope equipped with a modern high performance coronagraph to resolve the habitable zone at high contrast and directly image any potentially habitable planet that may exist in the system. Due to the extreme apparent brightness of the stars, exposure times can be as short as minutes with ideal components, or days with realistic ones. This makes it possible to do color photometry on potentially habitable planets sufficient to differentiate Venus-like, Earth-like, and Mars-like planets from each other and establish the presence of Earth-pressure atmosphere through Rayleigh scattering.

The raw contrast requirements for such an instrument can be relaxed to $1e-8$ if the mission spends 2 years collecting tens of thousands of images on the same target, enabling a factor of 500-1000 speckle suppression in post processing with a new technique called Orbital Differential Imaging (ODI). The light leak from both stars is controllable with a special wavefront control algorithm known as Multi-Star Wavefront Control (MSWC), which independently suppresses diffraction and aberrations from both stars using independent modes on the deformable mirror (see Thomas et al. at this conference).

The presentation will describe the general studies and calculations in more detail and briefly present examples of small coronagraphic mission concepts currently being developed to take advantage of this opportunity. (For more detail about one such concept, see Bendek et al. at this conference).

KEPLER MISSION: WHAT WE LEARNED AND HOW WE LEARNED IT

William Borucki, Kepler PI

At the time of the first Kepler proposal, no exoplanets had been discovered. At the conclusion of the Mission, over 4000 planetary candidates had been discovered and a new era of astronomy had opened. Planets have been found with average densities as low as Styrofoam (0.05 gr/cc) and as high as that of tungsten (17 gr/cc), and with sizes between that of the Moon to double that of Jupiter. Planets are found orbiting much closer to their star than Mercury does to the Sun, but Jupiter-size planets in such locations are rare. The high frequency of 4- and 5-planet systems indicates that flat systems are common. However, in about 20% of planetary systems, a planet is found orbiting at a large angle to the stellar equatorial plane. Very compact systems are common and many of the planets are in near-resonant orbits, but seldom in resonant orbits. Planets are found in binary and trinary star systems. Because circumbinary planets show very irregular transit signatures, most are found by visual inspection rather than by automated searches. Planets in the habitable zone are common. A combination of several observational and modeling techniques is used to deduce the characteristics of the planets and the host stars. Observational techniques include; high-precision radial velocity measurements to deduce planetary masses, spectroscopic observations to characterize host stars, adaptive optics, speckle, and HST to search for background stars that could account for the transit signal or dilute it, and Spitzer IR observations to check that the transits are achromatic. Analysis and modelling techniques include; asteroseismic analysis to determine stellar size age, and density from p- and g-mode observations, modeling techniques using Markov-chain Monte Carlo methods to get best-fit values for planetary and stellar parameters, statistical analysis to estimate the frequency of false-positive events, and stellar-evolution models to deduce stellar size and age. Because Kepler has observed over 170,000 stars nearly continuously for four years, many unusual stars have been found and the information needed for the determination of rotation rates of the cores of giant stars and the separation of those stars that are hydrogen-shell burning from those that are helium-burning has been obtained. A discussion of these results and the methods used to get the results will be presented.

FORMATION OF NUCLEOBASES FROM THE UV IRRADIATION OF PYRIMIDINE IN ASTROPHYSICAL ICE ANALOGS. Scott A. Sandford¹, Michel Nuevo^{1,2}, and Christopher K. Materese¹, ¹NASA Ames Research Center (Scott.A.Sandford@nasa.gov), ²BAER Institute.

Topic: Astrobiology

Nucleobases belong to either the pyrimidine-base group (uracil, cytosine, and thymine) or the purine-base group (adenine and guanine) and are the informational subunits of DNA and RNA. While several nucleobases have been detected in meteorites, the actual processes by which they are made in space have yet to be fully understood. We have been studying the formation of the pyrimidine-based nucleobases from the ultraviolet (UV) irradiation of pyrimidine in low-temperature ices containing H₂O, NH₃, CH₃OH, and/or CH₄ in order to simulate the astrophysical conditions under which prebiotic species may be formed in the interstellar medium, in the protosolar nebula, and on icy bodies of the Solar System.

Gas mixtures were prepared and deposited on aluminum foil held at <20 K while simultaneously irradiated with UV photons. After irradiation, samples were warmed to room temperature, and any remaining residues were recovered with water and analyzed with liquid and gas chromatographies. Experiments showed that this process leads to the formation of numerous photo-products, including the nucleobases uracil [1–3], cytosine [2], and thymine [3], and a number of their precursors [1–3] (Figure 1). In addition, other species of prebiotic interest such as urea and the amino acids glycine and alanine were also identified in the residues [2,3].

Interestingly, not all nucleobases are observed to be formed with the same efficiency. Our results show that the net oxidation and amination of pyrimidine are more efficient processes than methylation. Consequently, uracil and cytosine are made more efficiently than thymine. This is especially true when realistic ice compositions are used [4]. In a scenario in which molecules important for life, such as nucleobases, were formed via astrophysical ice photo-processes and delivered to the primitive Earth via comets and meteorites, our experimental results suggest that the abundance of uracil delivered may have been significantly higher than that of thymine. In addition, if the delivery of extraterrestrial nucleobases to Earth played a role in the origin of life, the over-abundance of uracil (an RNA base) over that of thymine (a DNA base) may have contributed to the initial emergence of molecular world dominated by RNA rather than DNA.

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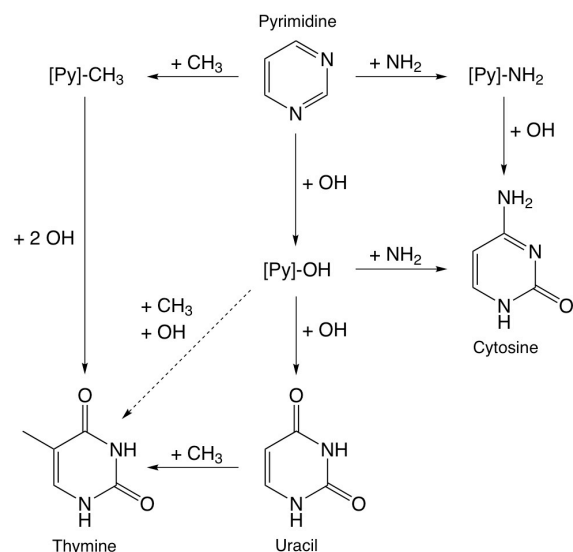


Fig. 1. Pathways leading to the formation of uracil, cytosine, and thymine from the UV photo-irradiation of pyrimidine in H₂O-, NH₃-, CH₃OH-, and/or CH₄-containing ices [15].

Search for Sugars and Related Compounds in Residues Produced from the UV Irradiation of Astrophysical Ice Analogs

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Topic: Astrobiology

A large variety and number of organic compounds of biological and prebiotic interests have been detected in meteorites, including sugars and related compounds such as sugar acids and sugar alcohols.¹ The presence of these compounds in meteorites, along with amino acids, amphiphiles, and nucleobases,²⁻⁶ strongly suggests that molecules essential to life can be formed abiotically under astrophysical conditions. This hypothesis is supported by extensive laboratory studies on the formation of complex organic molecules from the ultraviolet (UV) irradiation of astrophysical ice analogs (H₂O, CO, CO₂, CH₃OH, CH₄, NH₃, etc.). In particular, these studies show that the organic residues recovered at room temperature after the UV irradiation of such ice mixtures contain amino acids,⁷⁻⁹ amphiphiles,⁴ nucleobases,¹⁰⁻¹³ as well as other organic complex organic compounds.^{14,15}

However, to the best of our knowledge, no systematic search for the presence of sugars, sugar acids, and sugar alcohols in laboratory residues have been reported to date, despite the fact that those compounds are involved in a large number of biological processes. Only a limited number of small (fewer than 3 carbon atoms) sugar derivatives such as glycerol and glyceric acid have been detected in residues.¹⁴ In this work, we show preliminary results obtained from the systematic search for sugars and sugar-related compounds in organic residues produced from the UV irradiation of CH₃OH and H₂O+CH₃OH ices, and compare our experimental data with measurements of these compounds in primitive meteorites.

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Meteoritic Sugar Derivatives: Enantiomer Excesses And Laboratory Attempts At Duplication.

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Science Topic: Astrobiology

Introduction: Carbonaceous meteorites contain several classes of organic compounds of interest in the study of prebiotic chemistry including the chemistry of the origin of life. Identified compounds include carboxylic acids, amino acids, and sugar derivatives [1, 2]. Many of these compounds are chiral: they are composed of two non-superimposable mirror images called "enantiomers". Such molecules are important on Earth because biological polymers (proteins, nucleic acids, etc.) are homochiral meaning their monomers consist of only one of the two enantiomers. In contrast, naturally occurring (non-biological) processes that take place today or in the early Solar System are generally assumed to produce racemic mixtures, i.e., equal amounts of the two enantiomers. For example, racemic mixtures are the norm in the majority of analyzed meteoritic chiral compounds [2, 3]. However, as originally shown by Cronin and Pizzarello [4], some of the more unusual amino acids contain slightly more of one enantiomer (the "L" enantiomer). These excesses have been confirmed by ¹³C and D isotopic analyses that also point to cold interstellar origins for the formation of precursor compounds. The origins of the enantiomer enrichments are still subject to debate, however the findings may have implications for the origins of homochirality on Earth.

In the case of the origin(s) of enantiomer excesses in meteoritic amino acids, plausible mechanisms include the preferential destruction of one enantiomer of a given compound by circularly polarized UV light [5] or the synthesis of slightly more of one enantiomer under simulated interstellar conditions [6, 7]. Mechanisms utilizing magnetochiral effects have been shown to produce small ($\sim 10^{-4}$) enantiomer excesses in an initially racemic (pre-made) metal-organic compound [8]. Previously, we identified several chiral sugar derivatives in carbonaceous meteorites and a preliminary analysis revealed anomalous D-enantiomer enrichments in some of the sugar acids [9]. This presentation will focus on updated molecular and enantiomer analyses of meteoritic sugar derivatives including sugar alcohols. It will also include the results of attempts at laboratory recreation of such excesses. If the forces that acted on organic compounds (and/or their precursors) in the early Solar System are common, then specific laboratory experiments may indicate whether enantiomer excesses in organic compounds are available for the origin of life in a multitude of planetary systems.

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Searching for the prebiotic origins of citric acid cycle metabolites: a mechanistic investigation based on the abiotic chemistry of pyruvic acid.

Andro C. Rios, Exobiology Branch, NASA Postdoctoral Program Fellow, Oak Ridge Associated Universities, andro.c.rios@nasa.gov

George Cooper, Exobiology Branch, NASA Ames Research Center

Science Topic: Astrobiology

Pyruvic acid is a small organic molecule that is vital to all cellular metabolism. It has recently been detected in carbonaceous meteorites indicating that it can be formed from abiotic processes and might have been present before the origin of life (1). It was also reported that pyruvic acid has the intrinsic ability to produce many of the intermediary metabolites associated with the citric acid cycle (1). These observations have led us and others to hypothesize that the natural chemistry of pyruvic acid may have played a role in the emergence of a proto-metabolism (2-5). In extant cells, chemical reactions associated with the citric acid cycle are carried out by the action of highly evolved enzymes, but it is assumed that in a prebiotic epoch, enzymes could not have been present to produce the citric acid cycle intermediates. We are investigating the abiotic chemistry of pyruvic acid under alkaline conditions in order to elucidate the mechanisms for how pyruvic acid can lead to the production of intermediary metabolites (i.e., oxaloacetic acid, malic acid, isocitric, citric acid, fumaric acid, etc.). Understanding the molecular pathway for these reactions is the only way to determine if all of the citric acid cycle metabolites share a common precursor or set of related precursors that might have been incorporated in a proto-metabolic cycle. Results from these studies including proposed mechanistic pathways will be presented.

References

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Title: Upper Atmosphere Detection of Meteoritic Organics by a Mid-Infrared Small Satellite Spectrometer (MIRSSS)

Authors: D. P. Summers, A. Colaprete, A.J. Ricco, N. Bramall, K.A. Ennico, D. Landis, D.D. Squires

Science Topic: Astrobiology

Introduction:

The objective of this mission is to detect exogenous organics being delivered by meteors and interplanetary dust particles to the upper atmosphere and to quantify and characterize the delivered organics.

Organics could survive ablation upon atmospheric entry because they undergo too few collisions to be destroyed and the entrainment of meteoritic material will lower the oxidation level of the train. The detection of a C–H stretch emission in persistent meteor trains has been observed. Material is also being delivered as interplanetary dust particles and settling through the atmosphere. This material provides the bulk of the mass influx but little is known about the amounts of material being delivered, how it survives, or in what forms it may survive.

Mission:

This mission would put a mid-infrared telescope/spectrometer into low Earth orbit. Once there, this instrument would use solar occlusion of the upper atmosphere, along a viewing path that grazes the Earth's atmosphere in the 80 to 100 km altitude region, to obtain long-path-length IR absorption spectra. This will provide a sensitive way of detecting the presence of delivered organic material by the mid-IR absorbance of molecular bands. It would be designed to fit into a 6U small satellite footprint and would be capable of a sensitivity of 2.2% transmittance or better. It will have a spectral resolution of 6 cm⁻¹. We will capitalize on BioSentinel's development at Ames Research Center by utilizing the nearly identical SC bus, thus leveraging existing NASA investment. This bus will provide 4U and 5.3 kg of payload volume and mass, with 15 W average power to the payload. It includes a star-tracker-based 3-axis attitude control system expected to provide better than 0.1° pointing stability.

Impact:

The data from this mission will let us characterize the amounts of meteoritic organic material being delivered to the upper atmosphere and understand how much of it survives. The use of infrared characterization will provide some understanding of the nature of the organics and so will also help us understand the types of material being delivered. By a better understanding of the material that gets delivered, we can constrain and better consider the nature of the extraterrestrial source material. This mission will help us understand how such material contributed to prebiotic chemistry and the origins of life.

These results will help us better understand the origin of life on Earth and also the potential for life on Mars and Europa. It would inform us about the prebiotic chemistry on these bodies and possible presence of organics on others. It would help us understand the asteroids and comets that represent sources of extraterrestrial material.

Ground Control Experiments and Flight Sample Preparation for the International Space Station OREOcube: ORganics Exposure in Orbit Experiment. Kathryn Bryson (SSA), Andrew Mattioda (SSA), Antonio Ricco (RD), Farid Salama (SSA), Orlando Santos (SSX), Richard C. Quinn (SST)

Science Topic: Astrobiology

Introduction: The ORganics Exposure in Orbit (OREOcube) experiment is designed to measure chemical changes in organic samples in contact with inorganic substrates to investigate the role solid mineral surfaces may play in the (photo)chemical evolution and distribution of organics in the interstellar medium, comets, meteorites, and other bodies. Currently under development in preparation for a 12-month deployment on an International Space Station (ISS) external platform, OREOcube uses UV/visible/near-IR spectroscopy for *in situ* sample measurement. Based on technology developed by the NASA Ames Research Center's Small Spacecraft Payloads and Technologies Team, OREOcube is comprised of two 10-cm cubes each containing a highly advanced spectrometer for the monitoring of samples held in a 24-sample cell carrier. Each cube is an autonomous stand-alone instrument package, requiring only a power-and-data interface, with integrated electronics, a microcontroller, data storage, and optics to enable the use of the Sun for photochemical studies (in the 124 to 2600 nm range) and as a light source for spectroscopy (Fig. 1).

The OREOcube experiment: In an OREOcube experiment, an adsorbate-substrate interface is defined by depositing organic samples as thin films onto solid inorganic substrates. This provides a controlled method to examine organic samples and inorganic surface interactions. Surfaces provide multiple mechanistic pathways that can impact chemical transformations of organic molecules exposed to radiation. Depending on

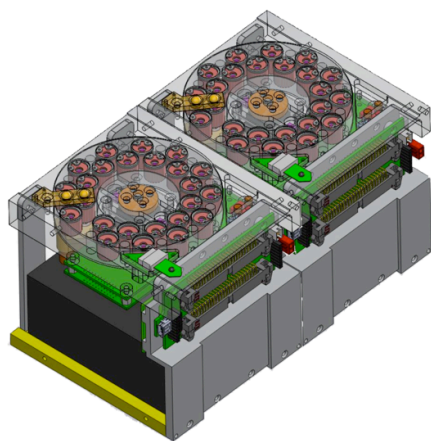


Fig. 1. OREOcube payload. Two independent 10-cm cubes each containing a 24-sample cell carrier and an integrated UV/Vis/NIR spectrometer are used to measure changes in in organic compounds exposed to low-Earth-orbit radiation conditions on an ISS external platform.

the nature of the substrate, both physi- and chemisorption can result in new photochemical processes in both the adsorbate and the surface. Samples are housed in hermetically sealed reaction cells containing an internal test environment that allows control of headspace gases including the partial pressure of water vapor. The sealed sample cell also allows for the study of chemical processes related to atmospheric chemistry (e.g., Titan).

Figure 2 shows spectra of OREOcube ground control iron tetraphenylporphyrin samples deposited on iron nickel (90/10) (A) and magnetite (B). The spectra are presented before and after approx. 500 hrs. of simulated solar exposure. The changes in the thin film are more pronounced on the sample on iron nickel than magnetite. By using thin-film samples, changes in UV/Vis/NIR absorption bands can be measured as a function of time. By measuring chemical changes *in situ*, OREOcube will provide data sets that capture critical kinetic and mechanistic details of sample reactions in real time, something that is not obtainable with the current exposure facilities on the ISS.

Acknowledgements: The OREOcube project is a

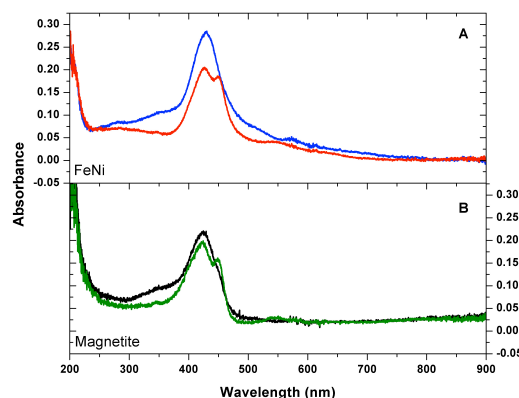


Fig. 2. Spectra of OREOcube iron tetraphenylporphyrin samples before and after approx. 500 h of simulated solar exposure. Panel A is deposited on iron nickel (blue before exposure and red after exposure). Panel B is deposited on magnetite (black before and green after exposure).

ESA-NASA collaboration. U.S. science team participation in OREOcube is funded by the NASA Astrobiology Science and Technology Instrument Development Program. The ESA PI is P. Ehrenfreund and the European OREOcube science team includes: A. Elsaesser, H. Cottin, E. Dartois, L. d'Hendecourt, R. Demets, B. Foing, Z. Martins, M. Sephton and M. Spaans.

The structure and chemical layering of Proterozoic stromatolites in the Mojave Desert

S. Douglas^{1,2}, M.E. Perry^{3,4}, W.J. Abbey⁵, Z. Tanaka^{4,6}, B. Chen^{4,6}, C.P. McKay⁴¹Planetary Science Institute, Tucson, AZ, 85719²East Los Angeles College, Monterey Park, CA 91754³University of Pennsylvania, Philadelphia PA 19104⁴NASA Ames Research Center, Moffett Field CA 940356⁵JPL, Pasadena, CA 91109⁶Dept of Electrical Engineering, UC Santa Cruz, Santa Cruz, CA 95060Corresponding author: chris.mckay@nasa.gov*In press Int. J. Astrobiology, 2015*

The Proterozoic carbonate stromatolites of the Pahrump Group from the Crystal Spring formation exhibit interesting layering patterns. In continuous vertical formations there are sections of chevron-shaped stromatolites alternating with sections of simple horizontal layering. This apparent cycle of stromatolite formation and lack of formation repeats several times over a vertical distance of at least 30 m at the locality investigated. Small representative samples from each layer were taken and analyzed using X-ray diffraction (XRD), X-ray fluorescence (XRF), environmental scanning electron microscopy – energy dispersive X-ray spectrometry (ESEM-EDS), and were optically analyzed in thin section. Optical and spectroscopic analysis of stromatolite and of non-stromatolite samples were undertaken with the objective of determining the differences between them. Elemental analysis of samples from within each of the four stromatolite layers and the four intervening layers shows that the two types of layers are chemically and mineralogically distinct. In the layers that contain stromatolites the Ca/Si ratio is high; in layers without stromatolites the Ca/Si ratio is low. In the high Si layers, both K and Al are positively correlated with the presence and levels of Si. This, together with XRD analysis, suggested a high K-feldspar (microcline) content in the non-stromatolitic layers. This variation between these two types of rock, could be due to changes in biological growth rates in an otherwise uniform environment or variations in detrital influx and the resultant impact on biology. The current analysis does not allow us to choose between these two alternatives. A Mars rover would have adequate resolution to image these structures and instrumentation capable of conducting a similar elemental analysis.

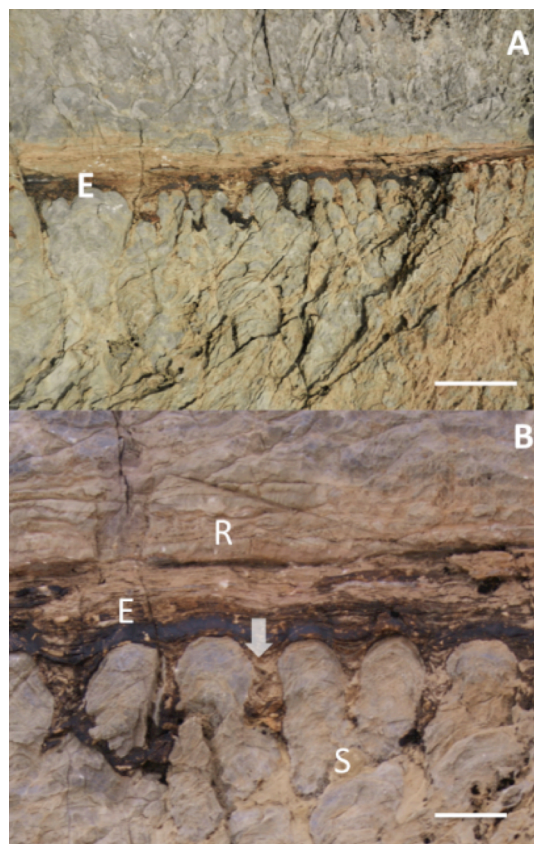


Figure 1. A: Field image of a portion of the outcrop, showing an event layer (E), and the top of a stromatolite layer below it (S) and a recovery layer above it (R). B: Close up view of the same area as shown in A. The material forming the event layer can be seen filling the gaps between stromatolite heads (arrow).

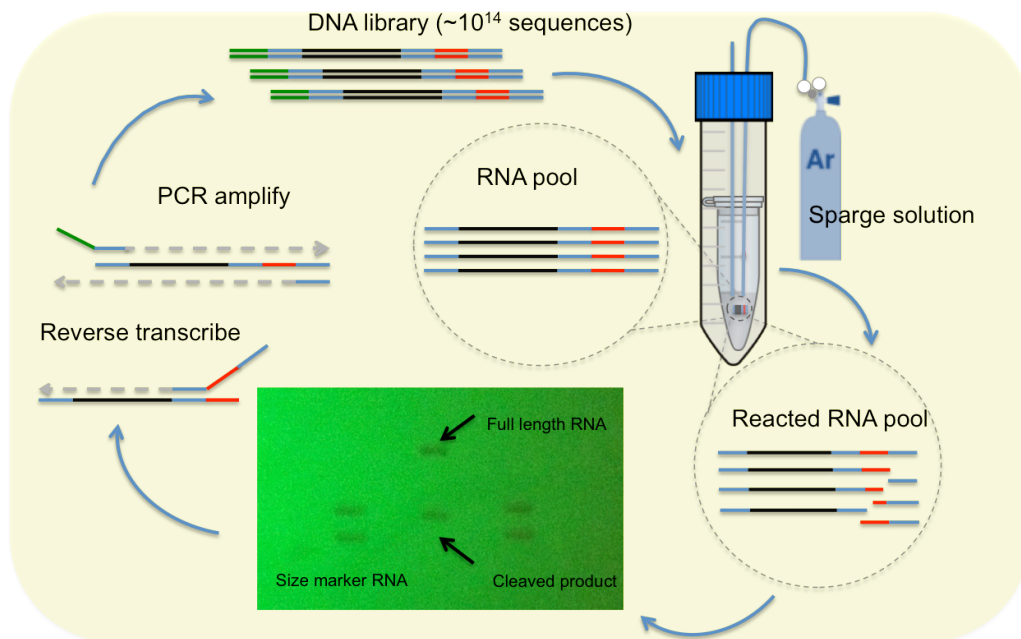
***In vitro* evolution of distinct self-cleaving ribozymes from alternate environments**

Astrobiology

Milena Popović, James Stephenson, Palmer Fliss, Mark Ditzler

Abstract:

In vitro evolution of RNA offers insight into the functional capabilities of RNA, including its ability to support catalysis. Understanding the potential of RNA to support catalysis requires a determination of the impact of the local environment on the distribution of functional RNAs in sequence space. The narrow range of conditions used to explore random sequence space for functional RNAs has limited the understanding of the effects of chemical milieu on RNA function. To test the impact of environmental factors relevant to RNA's potential role in the origin of life on earth, we evolved populations of self-cleaving ribozymes in an anoxic atmosphere with varying pH in the presence of either Fe^{2+} or Mg^{2+} . From the same starting RNA pool, we also evolved self-cleaving ribozymes in the presence of montmorillonite clay. Ferrous iron was abundant on the early earth and likely played a critical role in the emergence of life. Comparing RNA populations evolved with Mg^{2+} to those evolved with Fe^{2+} shows that these two ions significantly impact the evolution of RNA catalysis at both neutral and acidic pH. Furthermore, pH displays a dramatic impact on the evolution of RNA catalysis in the presence of either Mg^{2+} or Fe^{2+} . Populations evolved under each of the four conditions tested are dominated by different RNA sequences, revealing global differences in the underlying fitness landscapes. This result demonstrates the importance of counterion identity and pH in establishing the potential role of RNA in transitioning from chemistry to biology.



A Kepler Galaxy Survey Establishing the Temporal Baseline for Extragalactic Systems

Michael N. Fanelli,
NASA Ames Research Center & Bay Area Environmental Research Institute

Pamela M. Marcum
NASA Ames Research Center

Jeff Van Cleve
NASA Ames Research Center & Universities Space Research Association

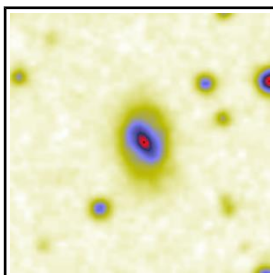
TOPIC: Astrophysics

ABSTRACT

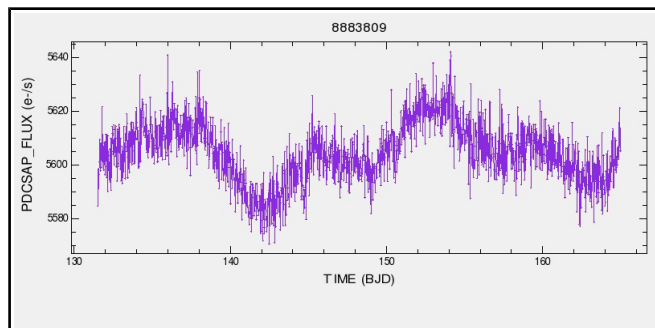
The Kepler / K2 Mission's combination of exquisite photometric precision and long-term near-continuous observing cadence permits new insight on galaxies, not previously achievable. Kepler's global monitoring of galaxies permits us to: (1) assess the photometric stability of galactic systems over a range of amplitudes and timescales, (2) quantify the existence and amplitude of AGN signals in galaxy cores, (3) provide a direct measure of supernovae rates across galaxy types, complementary to ground-based supernova searches, (4) measure the early brightening of any detected supernova, and (5) detect low-level transient variability from embedded active nuclei, highly luminous stars, and other compact objects.

Here we provide an update on our long-term program of assessing all galaxies observed during the Kepler prime mission along with initial analysis of a subset of galaxies monitored during K2 Campaigns 0 and 1. We focus on the ~2000 individual light curves of ~150 galaxies observed from Q3 through Q16. A number of systems exhibit continuous variations at the sub-millimag level; several systems show variable behavior in 1-2 quarters but are otherwise quiescent in other quarters. Based on the inspection of on average 8 quarters of data for ~300 systems, the observed occurrence rate of nuclear variability in galaxies > 1 mmag is found to be on order 2-3%. Four supernovae have been identified.

We also provide a status report on the Kepler Galaxy Legacy Archive and the prospects for extragalactic science with K2. The archive federates the time series photometry with morphological and photometric parameters for each galaxy along with observing logs and photometric statistics derived from the light curves. An associated software toolkit for Kepler data analysis, coded in IDL, is also described.



KIC 8883809 - a S0 galaxy whose variability was first detected using Kepler.



Q1 (discovery) light curve, which permitted identification as a candidate AGN.

This project is supported through NASA Astrophysics & Data Analysis Program Grant **NNX13AF17G**

Title: Large Scale Black Hole-Driven Outflows in Giant Elliptical Galaxies

Authors: P. Temi, F. Brighenti, W. G. Mathews, A. Amblard

Science Topic: Astrophysics

Abstract

Far-infrared dust emission from elliptical galaxies informs us about galaxy mergers, feedback energy outbursts from supermassive black holes and the age of galactic stars. We have investigated the role of AGN feedback observationally by looking for its signatures in elliptical galaxies at recent epochs in the nearby universe.

Remarkably, observations with Spitzer discovered a number of E galaxies with strong and spatially extended FIR emission from colder grains 5-10 kpc distant from the galaxy cores. Extended excess cold dust emission is interpreted as evidence of recent feedback-generated AGN energy outbursts in these galaxies, visible only in the FIR, from buoyant gaseous outflows from the galaxy cores.

Recent ALMA CO observations of local AGN have revealed a surprising new outflow component: the cold gas. AGN powered molecular outflows are now detected in a variety of systems, from isolated galaxies to giant ellipticals at the center of massive clusters. These cold outflows might well dominate the mass flow rate and are a key part of the AGN feedback process. Unfortunately, it is still unclear how common they are and how radio jets can accelerate cold and dense gas up to 103 km/s. In order to make progress in galaxy evolution studies it is imperative to understand how AGN outbursts impact the cold molecular gas.

*Resolved dust emission analysis in IC1459 and NGC2768.***A. Amblard, P. Temi**

Science Topic : Astrophysics

Elliptical galaxies are considered red and “dead” galaxies, due to their typical color and star formation rate (SFR). However, far-infrared(IR) MIPS Spitzer observations from Temi et al. 2007 revealed that some local elliptical galaxies possess an amount of dust beyond what can be lost by their star population. These observations suggest a potential feedback mechanism between the central AGN and the dusty gas, that transports buoyantly the dust several kpcs away from the core.

To better understand this feedback, we obtained PACS Herschel (70 and 160 μm) data for two galaxies, IC1459 and NGC2768, these data allow to map the cold dust at higher angular resolution (5.6” & 11.4”) . These two galaxies present a disturbed morphology at these far-infrared wavelengths that is very different from the smooth stellar light distribution expected from elliptical galaxies and observed in the optical and IR wavelengths for these galaxies.

In this work, we analyze the spectral energy distribution (SED) analysis of IC1459 and NGC2768, two local elliptical galaxies. We performed a pixel-by-pixel SED fitting of each of these objects, allowing us to characterize the spatial distribution of such parameters as the stellar mass, the SFR, the specific SFR (sSFR), the D4000 age, etc. Combining Herschel PACS and SPIRE data, both available for NGC2768, we estimate the dust mass and temperature distribution of this galaxy. We characterized the evolution of these properties with radius, and compared it to their metallicity gradient.

Title: Big Bursts of Star Formation from LITTLE THINGS¹: Starburst Triggers of Six Blue Compact Dwarf Galaxies

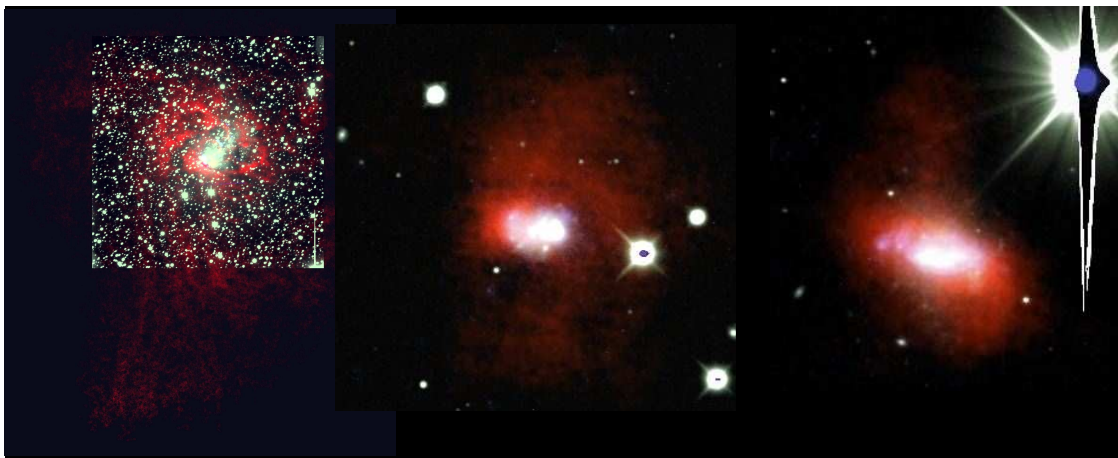
Authors: Trisha Ashley

Science Topic: Astrophysics

Abstract:

In dwarf galaxies it is still uncertain which processes contribute to star formation and how much they contribute to star formation. Blue compact dwarf (BCD) galaxies are low mass, low shear, gas rich galaxies that have high star formation rates when compared to other dwarf galaxies. What triggers the dense burst of star formation in BCDs but not other dwarfs is not well understood. It is often suggested that BCDs may have their starburst triggered by gravitational interactions with other galaxies, dwarf-dwarf galaxy mergers, or consumption of intergalactic gas. However, there are BCDs that appear isolated with respect to other galaxies, making an external disturbance unlikely.

I have studied six apparently isolated BCDs from the LITTLE THINGS sample in an attempt to understand what has triggered their burst of star formation. LITTLE THINGS is an H I survey of 41 dwarf galaxies. Each galaxy has high angular and velocity resolution H I data from the Very Large Array (VLA) telescope and ancillary stellar data. I use these data to study the detailed morphology and kinematics of each galaxy, looking for signatures of starburst triggers. In addition to the VLA data, I have collected Green Bank Telescope (GBT) data for the six BCDs. The high sensitivity, low resolution GBT data are used to search the surrounding area of each galaxy for extended emission and possible nearby companion galaxies. The GBT data result in no nearby, separate H I companions at the sensitivity of the data. However, the VLA data show evidence that each BCD has likely experienced some form of external disturbance despite their apparent isolation. These data therefore suggest that even though these BCDs appear isolated with respect to other galaxies, they have not been evolving in isolation.



¹ Local Irregulars That Trace Luminosity Extremes, The H I Nearby Galaxy Survey;
<https://science.nrao.edu/science/surveys/littlethings>

Title: Star Formation In All the Wrong Places, and Other Astronomical Puzzles, Revealed By the SOFIA Observatory

Author: Pamela Marcum and the SOFIA Mission

Science Topic: Astrophysics

Abstract:

The SOFIA (Stratospheric Observatory for Infrared Astronomy) program has just completed its Cycle 2 observations. In addition to providing observing time to the seven science instrument teams, SOFIA also supports international teams of Guest Investigators who are awarded observing time through an annual peer-reviewed proposal solicitation that is open to the entire astronomical community. As an airborne telescope optimized for infrared data collection, SOFIA offers the **only** regular access to the wide swath of infrared wavelengths obscured by Earth's lower atmosphere and unavailable to ground-based observatories.

The presentation will focus on scientific results, some surprise discoveries, and unique techniques resulting from recent SOFIA data. One dominant theme is how stars are able to form in extreme environments (Figure 1A) such as in the Galactic Center (Figure 1B), where energetic radiation fields and a hot, turbulent medium in the vicinity of a supermassive black hole would seemingly be unconducive to the observed prolific star production.

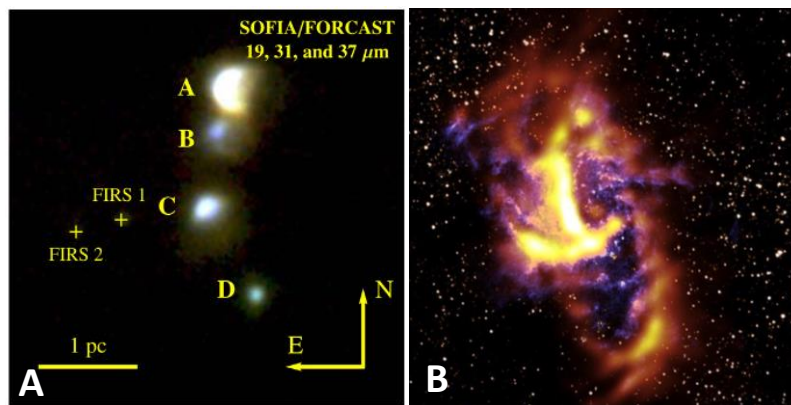


Figure 1 (A): A false-color image of the Galactic Center (orange) Warm dust shown by SOFIA/FORCAST, (purple) ionized gas and (white) stars shown by HST/NICMOS; (B): newly-formed massive stars in the turbulent environment of the Galactic Center: coincidence or expectation?

SOFIA offers unique tools for such studies, such as the ability to reveal “fossil” kinematic signatures showing the details of how a star forming cloud collapsed to its current state (Figure 2A), as well as providing “clocks” (Figure 2B) capable of directly measuring the collapse timescales for comparison to theoretical predictions.

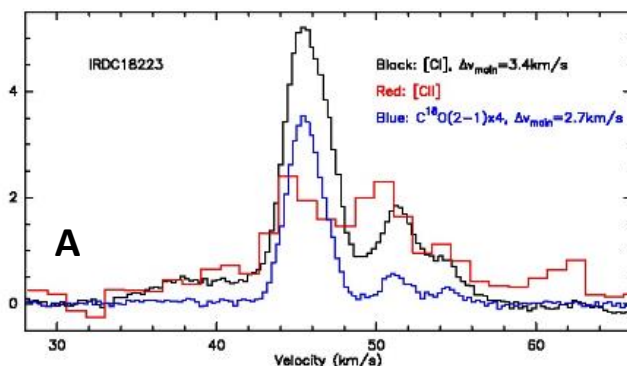
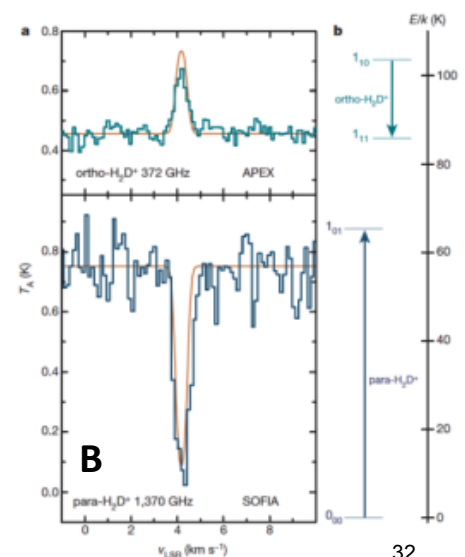


Figure 2 (A) comparison of velocity fields of different carbon phases, to reveal old kinematic signatures. SOFIA/GREAT spectroscopy of singly-ionized carbon [CII] shown in red; (B) The ratio of the ortho-to-para abundance of the deuterated trihydrogen cation (H_2D^+) provides a direct measure of the age of a star forming cloud (top: ortho emission detected by ground-based sub-millimeter Space Science & Astrophysics, January 2015 by SOFIA/GREAT).



Title: Identifying New Molecules from Comparison of Herschel-HIFI Spectra with *ab initio* Computational Spectra

Authors: Naseem Rangwala, Sean Colgan, Timothy Lee, Xinchuan Huang & Ryan Fortenberry

Science Topic: Astrochemistry

Abstract: As part of my NPP work we will identify new molecules in the interstellar medium (ISM) by comparing a catalog of theoretical spectra generated by the NASA Ames quantum chemistry group with high-resolution astronomical line surveys by the HIFI instrument onboard the Herschel Space Observatory. This will provide the chemical inventory for these star forming regions, allowing astrochemists to establish or confirm a variety of chemical networks, understand organic chemistry associated with star formation, and inform the studies that investigate the supply pathways of key organic molecules in Earth-like planet formation. Once new molecules are identified, we will determine their abundances relative to the other molecules in the same source and derive physical conditions in the star-forming regions. In addition, we will propose complementary observations with the Atacama Large Millimeter Array (ALMA) and the Stratospheric Observatory for Infrared Astronomy (SOFIA) of the newly identified molecules and related species.

Title: Quantitative Calibration of the Interstellar PAH Emission Band Charge Proxy and Deriving Local Physical Conditions

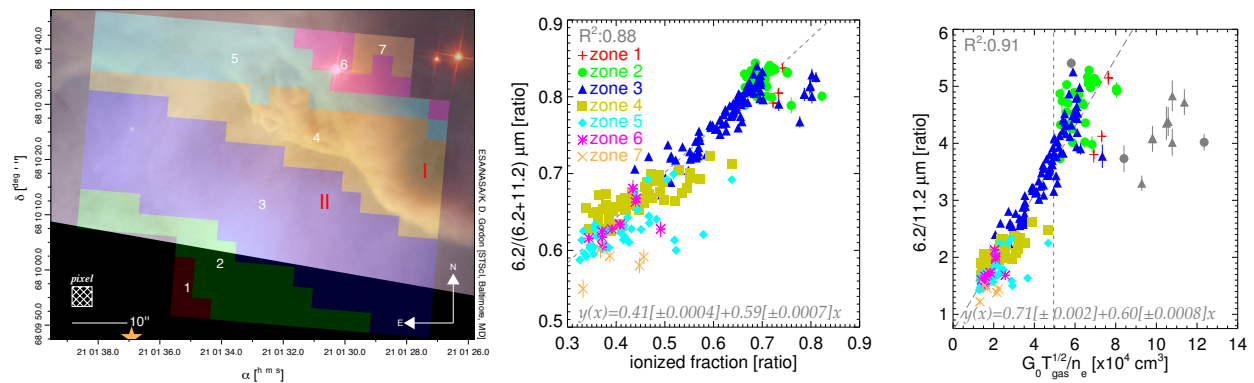
Authors: Christiaan Boersma, Jesse D. Bregman and Louis J. Allamandola

Science Topic: Astrophysics

Abstract:

Interstellar polycyclic aromatic hydrocarbons (PAHs), omnipresent across the Universe, play an intrinsic part in the formation of stars, planets and possibly even life itself. While PAH infrared emission features are now routinely used to trace star formation and as redshift indicators for distant, dust obscured, galaxies, the PAH spectra still contain a wealth of untapped information. This treasure trove of information will expand enormously with the launch of *JWST* later this decade. With its extreme sensitivity and unprecedented spectroscopic resolution, *JWST* will measure PAH spectra from a wide variety of objects spanning the Universe. The work presented here provides a step forward in developing new, *quantitative*, diagnostic tools that will help analyze these data.

Here, PAH emission in the *Spitzer*-IRS spectral map of the northwest photon dominated region in the Iris Nebula is analyzed exclusively using PAH spectra and tools of *The NASA Ames PAH IR Spectroscopic Database* (<http://www.astrochem.org/pahdb/>). The 5–15 μm spectrum at each pixel is fitted using an algorithm driven, quantitative, non-negative least-square fitting approach. The data are also analyzed using the more 'traditional' approach in which the PAH bands are isolated and their strengths measured without regard for their molecular origin. Band strength ratios are traditionally considered *qualitative* proxies for different properties of the state of the PAH population such as charge balance (i.e., the ratio of PAH^+ to PAH^0 and PAH^-). Combining the two analysis approaches allows, for the first time, to *quantitatively* calibrate the traditional PAH charge proxies, which can then be directly linked to local physical conditions. In the case of charge, local radiation field, gas temperature and electron density are probed using: $n_{\text{PAH}^+}/n_{\text{PAH}^0} = 3.76 \times 10^{-5} G_0 T_{\text{gas}}^{1/2}/n_e$.



Left: Composite *HST* image of the northwest photon dominated region in the Iris Nebula. PAH emission originates from the entire region. The field-of-view of the image coincides with the available *Spitzer*-IRS spectral map data. There is no *HST* data for the area shown in black. The crosshatched box labeled 'pixel' indicates the spectral extraction size. Overlain are seven zones identified by a *k*-means clustering analyses, numbered 1-7 and increasing with distance from HD 200775, which is indicated by the partial orange star. **Middle:** The 6.2/11.2 μm PAH charge proxy plotted versus the database fit determined ionization fraction. The color of each symbol indicates the numbered zone of origin presented in the left panel. Given is the linear best-fit equation and the squared linear relation coefficient for a straight line (R^2 ; dashed line). **Right:** Calibration of the 6.2/11.2 μm PAH band strength ratio as a function of a two state ionization parameter. The vertical short-dashed line locates approximately the boundary between the dense and diffuse medium. The symbols are consistent with that presented in middle panel for each of the numbered zones in the left panel. Outliers more than three standard deviations away from the data trend (beyond $\sim 8 \times 10^4$ on the x-axis and shown in gray) have not been used in the fit. Again, given are the linear best fit equation and the squared linear relation coefficient for a straight line (R^2 ; long-dashed line).

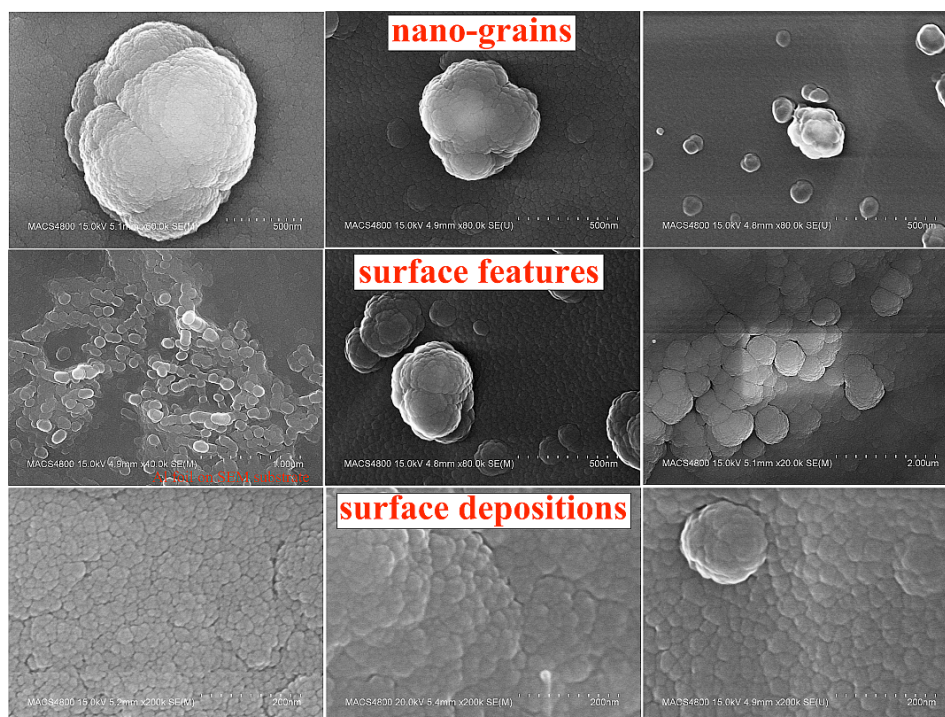
INVESTIGATIONS OF CARBONACEOUS GRAIN FORMATION FOR CIRCUMSTELLAR STUDIES

CESAR S. CONTRERAS, ELLA SCIAMMA-O'BRIEN, AND FARID SALAMA, Space Science and Astrobiology Division, NASA-Ames Research Center, Moffett Field, CA, USA.

Subjects: Laboratory Astrophysics, Circumstellar Carbon Dust, PAH

The study of formation and destruction processes of cosmic dust is essential to understand and to quantify the budget of extraterrestrial organic molecules. Although dust with all its components plays an important role in the evolution of interstellar chemistry and in the formation of organic molecules, little is known on the formation and destruction processes of carbonaceous dust. We report the progress that was recently achieved in this domain using NASA Ames' COSmIC facility (Contreras & Salama *ApJS* **2013**, *208*, 6 – 23). Polycyclic Aromatic Hydrocarbons (PAHs) are important chemical building blocks of interstellar dust. They are detected in interplanetary dust particles and in meteoritic samples. Additionally, observational, laboratory, and theoretical studies have shown that PAHs, in their neutral and ionized forms, are an important, ubiquitous component of the interstellar medium. The formation of PAHs from smaller molecules has not been extensively studied. Therefore, we have performed laboratory experiments to study the dynamic processes of carbon grain formation, starting from the smallest hydrocarbon molecules into the formation of larger PAH and further into nanograins. Studies of interstellar dust analogs formed from a variety of PAH and hydrocarbon precursors as well as species that include the atoms O, N, and S, have recently been performed in our laboratory using the COSmIC facility to provide conditions that simulate interstellar and circumstellar environments (Ricketts et al. *IJMS* **2011**, *300*, 26 – 30). We describe the formation of hydrocarbon soot using a pulsed slit nozzle discharge and the detection of product ions using the Reflectron time of flight mass spectrometer (ReTOF-MS). Investigation of soot material deposited on metal substrates was also conducted using scanning electron microscopy (SEM) at the UCSC/NASA Ames' Materials Analysis for Collaborative Science facility (<http://macs.advancedstudieslabs.org/>). The SEM analysis of the deposition of soot from methane and acetylene seeded argon plasmas provide examples on the types of nanoparticles and micrograins that are produced in these gas mixtures under the COSmIC experimental conditions. From these unique measurements, we derive information on the size and the structure of interstellar dust grain particles, the growth and the destruction processes of interstellar dust and the resulting budget of extraterrestrial organic molecules.

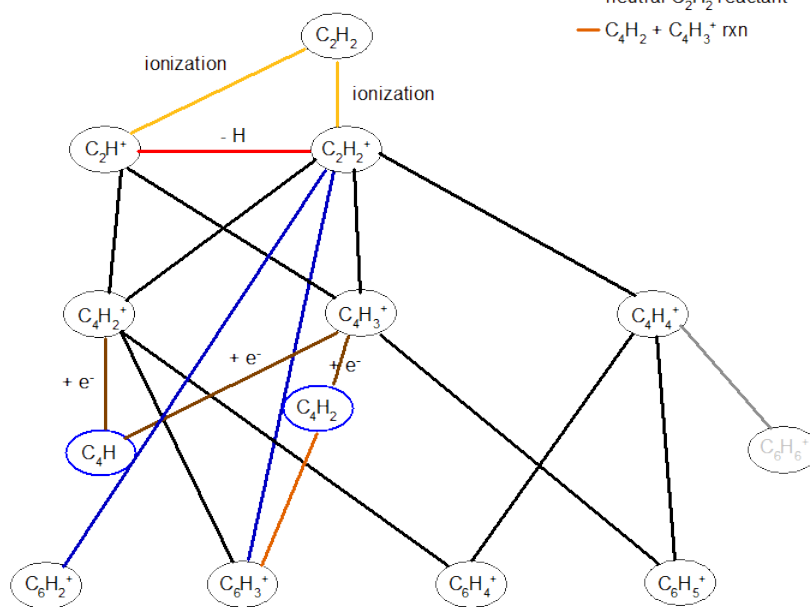
This work is supported by the NASA Science Mission Directorate (SMD) Astrophysical Research and Analysis (APRA) Program and NASA's Laboratory Astrophysics Carbon in the Galaxy's Consortium Grant. NASA grant NNX09AQ44A to University of California Santa Cruz is acknowledged for instruments in the UCSC MACS Facility within the UCSC/NASA-ARC ASL



CESAR S. CONTRERAS¹, ALEXANDER G.G.M. TIELENS², MICHAEL FRENKLACH³, AND FARID SALAMA¹, ¹Space Science and Astrobiology Division, NASA-Ames Research Center, Moffett Field, CA, USA. ²Leiden Observatory, Leiden University, The Netherlands. ³Mechanical Engineering Department, University of California, Berkeley, CA, USA.

The detection of organic molecules in interstellar and circumstellar space indicates that complex chemical reactions are taking place in these regions. Efforts to understand the formation and destruction processes of hydrocarbon-based molecules and particles are hindered since there is no direct method to study the reactions occurring in space. We report the progress that was recently achieved in this domain using NASA Ames' COSMIC facility (Contreras & Salama *ApJS* **2013**, 208, 6 – 23). Polycyclic Aromatic Hydrocarbons (PAHs) are important chemical building blocks of interstellar dust and their formation from smaller molecules has not been extensively studied. Therefore, we have performed laboratory experiments to study the dynamic processes of acetylene that lead to the formation of PAHs and further into nanograins. Studies of interstellar chemical analogs formed from a variety of PAH and hydrocarbon precursors as well as species that include the atoms O, N, and S, have recently been performed in our laboratory using the COSMIC facility to provide conditions that simulate interstellar and circumstellar environments (Ricketts et al. *IJMS* **2011**, 300, 26 – 30). In this work, we describe the chemical reactions that are most likely taking place in a pulsed slit nozzle discharge and the detection of product ions using the Reflectron time of flight mass spectrometer (ReTOF-MS). Chemical dynamics models were used to investigate the individual reaction steps that lead to the formation of larger ions for an acetylene seeded argon plasma. The most relevant chemical pathways that lead to the formation of the ion C_6H_5^+ are discussed.

- ionization
- hydrogen cleavage
- neutral C_4H_x reactant
- electron recombination
- neutral C_2H_2 reactant
- $C_4H_2 + C_2H_5^+$ rxn



Science topic: Astrophysics

Synthesis of Pure and N-substituted Cyclic Hydrocarbons (e.g. Pyrimidine) via Gas-Phase Ion-Molecule Reactions

Partha P. Bera,¹ Roberto Peverati,² Martin Head-Gordon,² and Timothy J. Lee¹

1. Space Science and Astrobiology Division, NASA Ames Research Center
2. University of California – Berkeley, Berkeley, CA

Large polyatomic carbonaceous molecules, known as polycyclic aromatic hydrocarbons, are known to exist in the outflows of carbon stars. How these large polyatomic molecules are synthesized in such exotic conditions is, thus far, unknown. Molecular ions, including positive and negative ions, are in relative abundance in the high radiation fields present under such conditions. Hence, barrierless ion-molecule interactions may play a major role in guiding molecules towards each other and initiating reactions. We study these condensation pathways to determine whether they are a viable means of forming large pure hydrocarbon molecules, and nitrogen-containing carbonaceous chains, stacks, and even cyclic compounds. By employing accurate quantum chemical methods we have investigated the processes of growth, structures, nature of bonding, mechanisms, and spectroscopic properties of the ensuing ionic products after pairing small carbon, hydrogen, and nitrogen-containing molecules. We have also studied the ion-neutral association pathways involving pure-carbon molecules e.g. acetylene, ethylene and other hydrocarbons, and their dissociation fragments in a plasma discharge as well as how nitrogen atoms are incorporated into the carbon ring during growth. Specifically, we explored the mechanisms by which the synthesis of pyrimidine will be feasible in the gas phase in conjunction with ion-mobility experiments. We have used accurate *ab initio* coupled cluster theory, Møller-Plesset and Z-averaged perturbation theories, density functional theory, and coupled cluster theory quantum chemical methods together with large correlation consistent basis sets in these investigations. We found that a series of hydrocarbons with a specific stoichiometric composition prefers cyclic molecule formation rather than chains. Some of the association products we investigated have large oscillator strengths for charge-transfer type electronic excitations in the near infrared and visible regions of the electromagnetic spectrum.

P. P. Bera, Martin Head-Gordon, and Timothy J. Lee *Astron & Astrophys.* 535, A74 (2011)
P. P. Bera, M. Head-Gordon, and T. J. Lee, 15, 2012-2023, *Phys. Chem. Chem. Phys.* (2013)
P. P. Bera, Roberto Peverati, M. Head-Gordon, and Timothy J. Lee, Submitted (2014)
A. Hamid, P. P. Bera, T. J. Lee, S. G. Aziz, A. O. Alioub, and M. S. El-Shal, 5, 3392 (2014)

Instrument design to directly image the HZ of Alpha Centauri

Eduardo A. Bendek, Ruslan Belikov, Sandrine Thomas, Julien Lozi, Jared Males, and the NASA Ames Mission Design Center

Science topic: Exoplanet detection, Direct Imaging, Instrumentation, Telescopes.

ABSTRACT

Missions to directly image and characterize identifying Earth-like planets (which we define as 0.5-2.0 Earth size) within the habitable zone around our nearest star system, Alpha Centauri (A and B stars), are being studied and proposed. The increasing scientific interest on this system is based on consistent increase of such planets frequency estimation. Based on model and latest analysis of the Kepler mission statistics this value could be as high as 55% per star, implying an 80% probability of such a planet existing in the Alpha Centauri system. Alpha Cen A&B are relatively bright stars (G2 and K1) driving the inner edge of the HZ to angular separations of 0.7" and 0.4" respectively. This enables direct imaging of the system with a 30cm class telescope. Contrast ratios in the order of 10^{10} are needed to image 1.0 Earth-brightness planets. Low-resolution (5-band) spectra of all planets, will allow establishing the presence and amount of an atmosphere. This star system configuration is optimal for and specialized small, and stable space telescope, that can achieve high-contrast but has limited resolution.

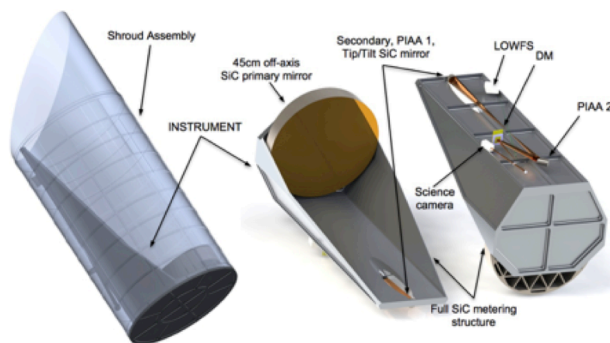


Figure 1: Instrument optics, metering structure and shroud

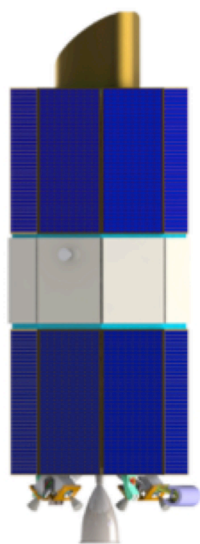


Figure 2: Spacecraft

This paper describes an innovative instrument design and a mission concept based on a full Silicon Carbide off-axis telescope, which has a PIAA coronagraph embedded on the secondary and tertiary mirrors of the telescope. This architecture maximizes stability and throughput. The Multi-Star Wave Front algorithm is implemented to drive a Kilo DM Deformable Mirror controlling simultaneously diffracted light from the on-axis and binary companion star. The instrument has a Focal Plane Occulter to reject starlight into a Low Order Wavefront Sensor that delivers high-precision pointing control. A set of five dichroics allows simultaneous multi-spectral (5-band) imaging of the system on photo counting detector such the EMCCD-201-20. Finally we utilize the ODI post-processing method that takes advantage of a highly stable environment (Earth-trailing orbit) and a continuous sequence of images spanning 2 years, to reduce the final noise floor in post processing to $\sim 1e-11$ levels, enabling high confidence and at least 90% completeness detections of Earth-like planets.

Title: [A method to directly image exoplanets in multi-star systems such as Alpha-Centauri](#)

Authors: S. Thomas, R. Belikov, E. Bendek.

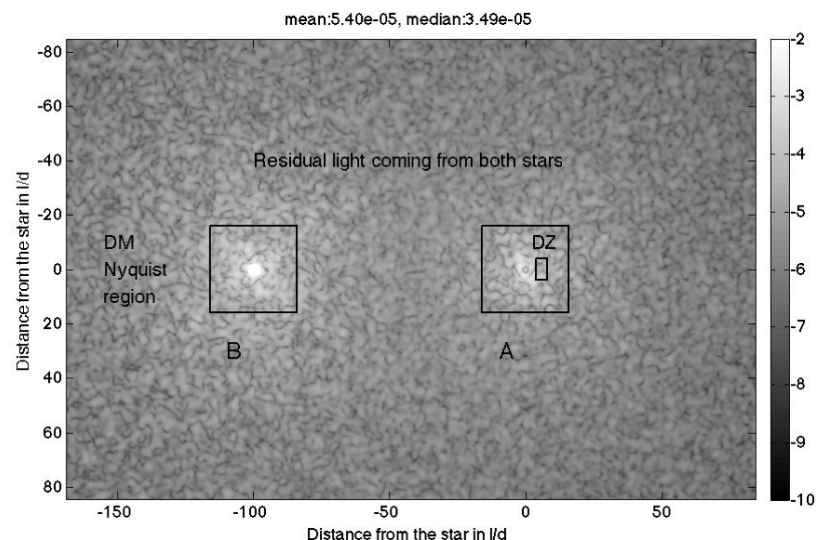
Science Topic: Exoplanets

Abstract: Direct imaging of extra-solar planets is now a reality, especially with the deployment and commissioning of the first generation of specialized ground-based instruments such as the Gemini Planet Imager and SPHERE. These systems will allow detection of Jupiter-like planets 10^7 times fainter than their host star. Obtaining this contrast level and beyond requires the combination of a coronagraph to suppress light coming from the host star and a wavefront control system including a deformable mirror (DM) to remove residual starlight (speckles) created by the imperfections of telescope.

However, all these current and future systems focus on detecting faint planets around a single host star or unresolved binaries/multiples, while several targets or planet candidates are located around nearby binary stars such as our neighboring star Alpha Centauri.

Here, we present a method to simultaneously correct aberrations and diffraction of light coming from the target star as well as its companion star in order to reveal planets orbiting the target star. This method works even if the companion star is outside the control region of the DM (beyond its half-Nyquist frequency), by taking advantage of aliasing effects.

This work has been funded by the NASA ARC FY14 CIF/DIF award



Title: Laboratory Demonstration of EXCEDE Polychromatic Contrast in Vacuum

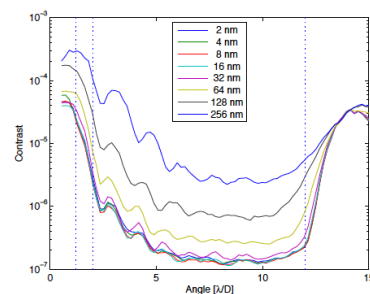
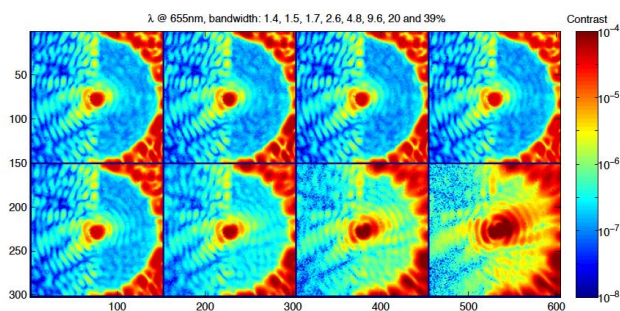
Authors: D. Sirbu, S. Thomas, R. Belikov, J.Lozi, E. Bendek., E. Pluzhnik, D. Lynch, T. Hix, P. Zell., G. Schneider, and O. Guyon

Science Topic: Exoplanets

Exoplanetary Circumstellar Environments and Disk Explorer (EXCEDE) is a proposed Explorer-class NASA space mission. It uses a 0.7-m diameter telescope with a Phase Induced Amplitude Apodization (PIAA) Coronagraph and a Deformable Mirror (DM) to create a “dark-hole” or a region of high-contrast starlight suppression at the focal plane to allow direct imaging of exoplanets. The ACE (Ames Coronagraph Experiment) group from NASA Ames is performing a laboratory demonstration to further the technology readiness of PIAA-C and wavefront control algorithms in polychromatic light, both in air and in vacuum

The PIAA architecture allows for an aggressive inner working angle for imaging the habitable zone of nearby solar systems. The contrast demonstration milestone is 10^{-6} (raw-contrast median) at an angular separation of $1.2\text{--}2 \lambda/D$ and simultaneously with 10^{-7} (raw-contrast median) between $2\text{--}4 \lambda/D$ at a central wavelength of 655 nm and a broadband bandwidth $\Delta\lambda/\lambda$ of 10%. Additionally, three raw contrast measurements must be provided with DM settings from scratch and maintained on the best 90% frames to demonstrate repeatability and stability of the dark hole region.

A laboratory demonstration of the EXCEDE mission’s high-contrast imaging capability is being carried out in vacuum at the Lockheed Martin Advanced Technology Center since January 2014. Key changes to the testbed architecture compared to the previous monochromatic milestone demonstration include using a vacuum facility, a lens-based inverse PIAA system, and a relocation of the DM prior to the PIAA mirrors which all reflect a configuration similar to space flight. We present the system architecture and results from the ongoing laboratory demonstration.



Title:**Highly Accurate Infrared Line Lists of SO₂ Isotopologues Computed for Atmospheric Modeling on Venus and Exoplanets**Authors:

Xinchuan Huang, David W. Schwenke, and Timothy J. Lee

Science Field: AstrochemistryAbstract

Recently we reported a semi-empirical $^{32}\text{S}^{16}\text{O}_2$ spectroscopic line list (denoted Ames-296K) for its atmospheric characterization in Venus and other Exoplanetary environments. In order to facilitate the Sulfur isotopic ratio and Sulfur chemistry model determination, now we present Ames-296K line lists for both 626 (upgraded) and other 4 symmetric isotopologues: 636, 646, 666 and 828. The line lists are computed on an *ab initio* potential energy surface refined with most reliable high resolution experimental data, using a high quality CCSD(T)/aug-cc-pV(Q+d)Z dipole moment surface. The most valuable part of our approach is to provide “truly reliable” predictions (and alternatives) for those unknown or hard-to-measure/ analyze spectra. This strategy has guaranteed the lists are the best available alternative for those wide spectra region missing from spectroscopic databases such as HITRAN and GEISA, where only very limited data exist for 626/646 and no Infrared data at all for 636/666 or other minor isotopologues. Our general line position accuracy up to 5000 cm^{-1} is $0.01 - 0.02\text{ cm}^{-1}$ or better. Most transition intensity deviations are less than 5% of experimentally measured quantities. The lists are compared to available models in CDMS / HITRAN and latest experiments. Results will benefit future interactions between theoretical and experimental efforts in SO₂ spectroscopy analysis.

The THS experiment: simulating Titan's atmospheric chemistry at low temperature (200K)

(Science Topic: Planetary Atmosphere & Climate)

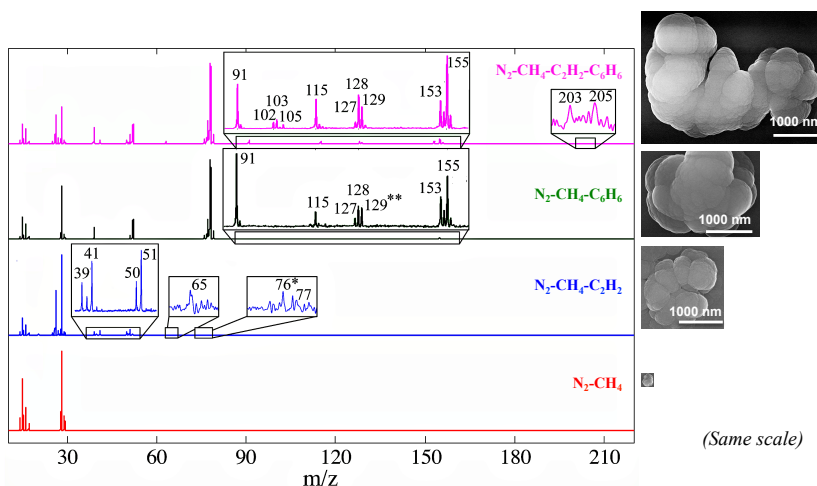
Ella Sciamma-O'Brien^{*1,2}, Kathleen Upton³, Jack L. Beauchamp³, Farid Salama¹¹NASA ARC, Moffett Field, CA, ²Bay Area Environmental Research Institute, Petaluma, CA, ³Noyes Laboratory of Chemical Physics and the Beckman Institute - Caltech, Pasadena, CA.

Titan, Saturn's largest moon, is the only solid body in the outer solar system with a dense atmosphere. In Titan's atmosphere, composed mainly of nitrogen (N_2 at 95-98%) and methane (CH_4 at 2-5%), a complex chemistry occurs at temperatures lower than 200 K, and leads to the production of heavy organic molecules and subsequently solid aerosols that form the orange haze surrounding Titan. Because the reactive carbon and nitrogen species present in Titan's aerosols could meet the functionality requirements for precursors to prebiotics, the study of Titan's aerosol has become a topic of extensive research in the fields of astrobiology and astrochemistry.

In the study presented here, we used the Titan Haze Simulation (THS) experiment, an experimental setup developed at the NASA Ames Cosmic simulation (COSmIC) facility to study Titan's atmospheric chemistry at low temperature, and produce aerosols representative of the early stages of Titan's aerosol formation. In the COSmIC/THS, the chemistry is simulated by plasma in the stream of a supersonic expansion. With this unique design, the gas is jet-cooled to Titan-like temperature ($\sim 150K$) *before* inducing the chemistry by plasma^[1], and remains at low temperature in the plasma discharge ($\sim 200K$). Because of the pulsed nature of the plasma, the residence time of the gas in the discharge is only a few microseconds, which leads to a truncated chemistry and allows for the study of the first and intermediate steps of the chemistry. Different N_2 - CH_4 -based gas mixtures can be injected in the plasma, with or without the addition of heavier precursors present as trace elements on Titan, in order to monitor the evolution of the chemical growth. Both the gas phase and solid phase products resulting from the plasma-induced chemistry can be monitored and analyzed using a combination of complementary *in situ* and *ex situ* diagnostics.

In a recently published study^[2], a mass spectrometry analysis of the gas phase has demonstrated that the COSmIC/THS is a unique tool to probe the first and intermediate steps of Titan's atmospheric chemistry at Titan-like temperature. In particular, the mass spectra obtained in a N_2 - CH_4 - C_2H_2 - C_6H_6 mixture are relevant for comparison to Cassini's CAPS-IBS instrument. The results of a complementary study of the

solid phase are consistent with the chemical growth evolution observed in the gas phase. Scanning Electron Microscopy images have shown that aggregates produced in N_2 - CH_4 - C_2H_2 - C_6H_6 mixtures are much larger (up to 5 μm in diameter) than those produced in N_2 - CH_4 mixtures (0.1-0.5 μm). Direct Analysis in Real Time mass spectrometry (DART-MS) combined with Collision Induced Dissociation (CID) have detected the presence



of aminoacetonitrile, a precursor of glycine, in the THS aerosols. X-ray Absorption Near Edge Structure (XANES) measurements also show the presence of imine and nitrile functional groups, showing evidence of nitrogen chemistry. These complementary studies show the high potential of COSmIC/THS to better understand Titan's chemistry and the origin of aerosol formation.

References: ^[1]Biennier et al., 2006, *Chem. Phys.* 326, 445. ^[2]Sciamma-O'Brien et al., 2014, *Icarus* 243, 325.

Acknowledgments: This research is supported by the NASA SMD PATM Program. K. T. Upton acknowledges the support of the NASA JFPF Program. The SEM images were obtained at the UCSC MACS Facility at Ames (NASA grant NNX09AQ44A to UCSC). The authors acknowledge the outstanding technical support of R. Walker and E. Quigley.

Possible formation of organic aerosols in Pluto's atmosphere

Hiroshi Imanaka (NASA Ames Research Center/SETI Institute), Dale P. Cruikshank (NASA Ames Research Center), Christopher R. Materese (NASA Ames), Christopher P. McKay (NASA Ames Research Center), Mark A. Smith (University of Houston)

Topic: Planetary Atmosphere & Climate

Abstract

Titan, Pluto, and Triton are the outer solar system bodies with nitrogen dominant atmospheres. Trace amount of gaseous methane and carbon monoxide are present, but with different CH_4/CO ratios. Considering the organic haze production in Titan's ionosphere, similar haze generation could occur in Pluto's thin atmosphere. However, the CH_4/CO ratios are substantially different in those bodies. Thus, it is not clear if similar haze formation could occur in Pluto's atmosphere as well. We have experimentally investigated the production rates of organic haze analogues in simulated atmospheres of Titan/Pluto/Triton from EUV-VUV radiation. In this study, we focus on their dependence on the CH_4/CO ratios and UV irradiation wavelengths between 50 – 150 nm. Our experimental results indicate that EUV photochemistry of a N_2/CO gas mixture can initiate the formation of aerosols even without CH_4 . Progressive CH_4 addition to the N_2/CO gas mixture generally increases the solid production rates. However, noticeable stepwise increase at CH_4/CO ration of ~ 0.1 - 0.2 was observed under our experimental conditions. A simulated Pluto gas mixture, $\text{N}_2/\text{CH}_4/\text{CO}$ (= 90/9/1), was irradiated at 60 nm to accumulate Pluto aerosol analogue. It shows significant difference in spectroscopic feature from Titan's N_2 - CH_4 UV aerosol analogue. Pale yellowish solid sample is relatively transparent in visible, and demonstrates a prominent aliphatic CH bonds at 3.4 μm . Our results imply that EUV-VUV photochemistry in Pluto's atmosphere may generate organic aerosol layers. However, the presence of CO could result in haze particles with very different chemical/optical properties from those in Titan. The New Horizon mission would reveal the detailed in 2015.

Title: Xenon Fractionation, Hydrogen Escape, and the Oxidation of the Earth

Author: Kevin Zahnle

Topic: Planetary Atmosphere & Climate (poster)

Xenon in Earth's atmosphere is severely mass fractionated and depleted compared to any plausible solar system source material, yet Kr is unfractionated. These observations seem to imply that Xe has escaped from Earth. But to date no process has been identified that can cause Xe, which is heavier than Kr, to escape while Kr does not. Vigorous hydrodynamic hydrogen escape can produce mass fractionation in heavy gases (Hunten et al. 1987, Sasaki & Nakazawa 1988, Pepin 1991). The required hydrogen flux is very high but within the possible range permitted by solar Extreme Ultraviolet radiation (EUV, which here means radiation at wavelengths short enough to be absorbed efficiently by hydrogen) heating when Earth was on the order of 100 Myrs old or younger. However this model cannot explain why Xe escapes but Kr does not.

Recently, what appears to be ancient atmospheric xenon has been recovered from several very ancient (3-3.5 Ga) terrestrial hydrothermal barites and cherts (Pujol 2011, 2013). What is eye-catching about this ancient Xe is that it is less fractionated than Xe in modern air. In other words, it appears that a process was active on Earth some 3 to 3.5 billion years ago that caused xenon to fractionate. By this time the Sun was no longer the EUV source that it used to be. If xenon was being fractionated by escape — currently the only viable hypothesis — it had to be in the less unfamiliar context of Earth's Archean atmosphere and under rather modest levels of EUV forcing. This requires a new model.

Here we address the circumstances in which Xe, but not Kr, could escape from Earth as an ion. In a hydrodynamically escaping hydrogen wind the hydrogen is partially photo-ionized. The key concepts are that ions are much more strongly coupled to the escaping flow than are neutrals (so that a relatively modest flow of H and H⁺ to space could carry Xe⁺ along with it), and that xenon alone among the noble gases is more easily ionized than hydrogen. This sort of escape is possible if not prevented by a planetary magnetic field. The best prospects for Earth are therefore escape along the polar field lines, although a very weak or absent magnetic field would likely work as well. As applied to the Archean Earth the discussion will be constrained by diffusion-limited hydrogen escape. The extended history of hydrogen escape implicit in Xe escape in the Archean is consistent with suggestions that hydrogen escape from the anoxic Archean atmosphere was considerable, because biogenic methane is expected to have been rather abundant. Hydrogen escape plausibly played the key role in creating oxidizing condition at the surface of the Earth and setting the stage for the creation of an O₂ atmosphere (Urey 1951, Hunten and Donahue 1976, Catling et al 2001, Zahnle et al 2013).

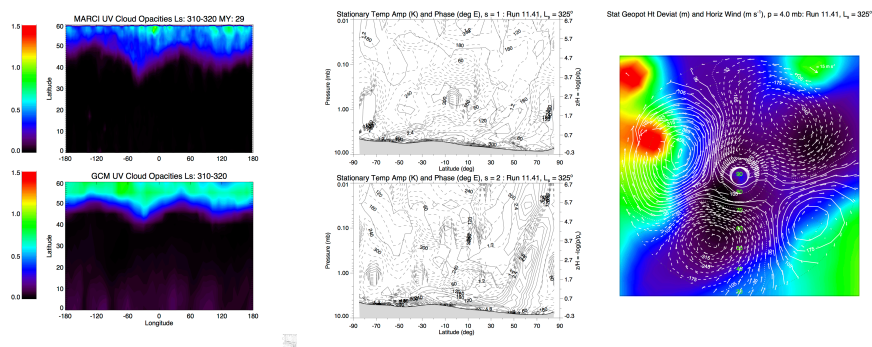
Catling DC et al (2001) *Science* 293, 839. Hunten, D.M., Donahue, T.M. (1976) *Ann. Rev. Earth Planet. Sci.* 4, 265. Pepin, R.O. (1991) *Icarus* 92, 2. Pujol M et al (2009) *GCA* 73, 6834. Pujol M et al (2011) *EPSL* 308, 298. Sasaki S, Nakazawa K (1988) *EPSL* 89, 323. Urey, H.C. (1952) *PNAS* 38, 351. Zahnle KJ et al (2013) *Chem. Geol.* 362, 26.

Title: Northern Late Winter Planetary Waves: MRO/MARCI Observations and Mars Climate Model Simulations

Authors: J.L. Hollingsworth*, M.A. Kahre*, R.M. Haberle*, M.J. Wolff** *NASA Ames Research Center, Moffett Field, CA, **Space Science Institute Boulder, Boulder, CO

Science Topic: Planetary Atmospheres and Climate

Abstract: As does Earth, Mars presents pronounced global atmospheric circulation patterns. Solar differential heating drives mean meridional overturning (Hadley) circulations which are deep and intense, are hemispherically asymmetric, and where a cross-equatorial single cell dominates. Within middle and high latitudes, thermally indirect eddy-driven (Ferrel) circulation cells have been indicated. Differently, however, large-amplitude orography on planetary and continental scales on Mars can force very non-Earth-like hemispheric circulation patterns. Recent observations from the Mars Reconnaissance Orbiter, "Mars Color Imager" (MARCI) instrument are utilized that emphasize water ice clouds in ultra-violet (UV) wavelengths, and these measurements have been binned into "daily global maps" (DGMs) of water-ice cloud optical depth. The presence of large-scale, extratropical quasi-stationary atmospheric wave disturbances in middle and late winter of the northern hemisphere have been found to be present in such DGMs. In combination with such observations, a full-physics Mars global climate model (NASA ARC marsgcm 2.1) is applied to place the observations into context. During late northern winter, it is found that strong, forced Rossby modes (i.e., planetary waves) exist, and with direct correlation to column-integrated cloud opacity undulating spatial patterns. At this season, zonal wavenumber $s = 2$ dominates (in contrast to wavenumber $s = 1$), consistent with MGS/TES analyses at this particular season (Banfield et al., 2003). Large-scale, planetary waves dictate the "coherence" of the northern polar vortex. Fundamentally, such forced planetary waves influence the polar vortex's impermeability (wave-induced) to tracer transport (e.g., dust and water-ice aerosol) and temporal mean water vapor spatial variations. The large-scale dynamical features of such planetary waves will be highlighted and discussed.



Title: Secular Climate Change on Mars: Is it Happening?

Authors: Robert M. Haberle, Melinda A. Kahre, Jeffery L. Hollingsworth, Planetary Systems Branch

Topic: Planetary Atmospheres and Climate

Abstract: The South Polar Residual Cap (SPRC) on Mars is an icy reservoir of CO₂. If all the CO₂ trapped in the SPRC were released to the atmosphere the mean annual global surface pressure would rise by ~20 Pa. Repeated MOC and HiRISE imaging of scarp retreat within the SPRC led to suggestions that the SPRC is losing mass. Estimates for the loss rate vary between 0.5 Pa per Mars Decade to 13 Pa per Mars Decade. Assuming 80% of this loss goes directly into the atmosphere, an estimate based on some modeling (Haberle and Kahre, 2010), and that the loss is monotonic, the global annual mean surface pressure should have increased between ~1-20 Pa since the Viking mission (~20 Mars years ago). Surface pressure measurements from a full Mars year of MSL data are used to detect this signal. Using the Ames GCM to compensate for dynamics and environmental differences, our analysis suggests that the mean annual pressure has *decreased* by ~8 Pa since Viking. This result implies that the SPRC has *gained* (not lost) mass since Viking. However, the estimated uncertainties in our analysis are easily at the 10 Pa level and possibly higher. Chief among these are the hydrostatic adjustment of surface pressure from grid point elevations to actual elevations and the simulated regional environmental conditions at the lander sites. For these reasons, the most reasonable conclusion is that there is no significant difference in the size of the atmosphere between now and Viking. This implies, but does not demand, that the mass of the SPRC has not changed since Viking. Of course, year-to-year variations are possible as implied by our analysis of the Phoenix data (not shown here). Given that there has been no unusual behavior in the climate system as observed by a variety of spacecraft at Mars since Phoenix, it seems more likely that the Phoenix data simply did not have a long enough record to accurately determine annual mean pressure changes as Haberle and Kahre (2010) cautioned. In the absence of a strong signal in the MSL data, we conclude that if the SPRC is losing mass it is not going into the atmosphere reservoir.

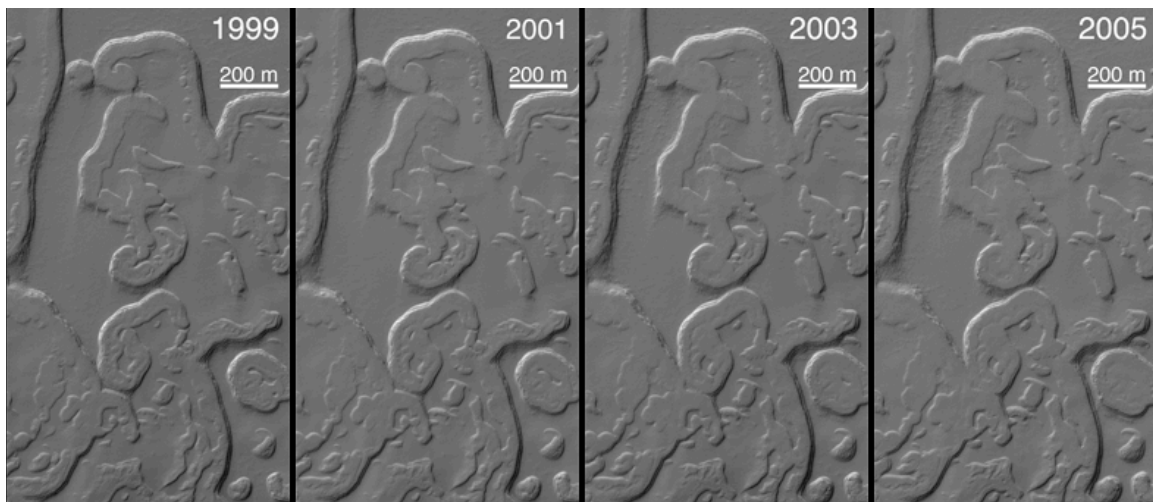


Figure 1. Scarp retreat in the South Polar Residual CO₂ ice cap over four consecutive Mars years.

Laboratory investigations of the complex refractory organic material produced from irradiation of Pluto ice analogs

Christopher K. Materese, Dale P. Cruikshank, Scott A. Sandford, Hiroshi Imanaka, Michel Nuevo

Topic: Planetary Science

Much of Pluto's surface consists of N₂, CH₄, and CO ices and combinations thereof. Radiation processing of these ices from cosmic ray bombardment can drive chemistry. Cosmic rays impacts onto the surface ice disperse much of their energy in the form of secondary electrons, which in turn drive much of the resulting chemical reactions. Laboratory experiments designed to simulate the surface conditions of icy surfaces in the Solar System can provide important insight into the chemistry driven by this radiation processing. Of particular interest to our effort is the characterization of any refractory organic residue produced from these ices. Recently, we have performed experiments to characterize the refractory materials produced from the UV photo-irradiation of N₂:CH₄:CO ices. These experiments showed the formation of organic compounds including several carboxylic acids,¹ indicating that photoprocessing of Pluto ices can lead to a complex chemistry. However, because Pluto's atmosphere is optically thick to Lyman- α UV radiation, it is important to re-examine the results using a more relevant radiation source.

In this work, we analyzed the refractory materials produced from the 1.2-keV electron bombardment of low-temperature N₂-, CH₄-, and CO-containing ices (100:1:1), which simulates the radiation from secondary electrons produced by cosmic rays bombardment impacting the surface ices of Pluto. The refractory organic materials were studied using multiple analytical techniques including infrared (IR) spectroscopy, X-ray absorption near-edge structure (XANES) spectroscopy, high resolution mass spectrometry (HRMS) and gas chromatography coupled with mass spectrometry (GC-MS).

Despite starting with extremely simple ices dominated by N₂, electron irradiation processing results in the production of refractory material with complex oxygen- and nitrogen-bearing organic molecules. Infrared spectra of the refractory material indicate the presence of O–H, N–H, C \equiv N, and C=O functional groups, which suggest the presence of alcohols, carboxylic acids, ketones, aldehydes, amines, and nitriles. XANES spectra of the material indicate the presence of carboxyl groups, amides, urea, and nitriles, and are thus consistent with the IR data. XANES data also provide atomic abundance ratios for the bulk composition of these residues. They show that the organic residues are extremely O- and N-rich, having ratios of N/C \sim 0.9 and O/C \sim 0.2. Finally, GC-MS data reveal that the residues contain urea as well as numerous carboxylic acids, some of which are of interest for prebiotic and biological chemistries. This work is timely because UV and near-IR spectroscopy of the surfaces of Pluto and Charon will be collected during the encounter with NASA's New Horizons spacecraft this year, and will provide the first close-up measurements of ices and their photoproducts.

[1] Materese, C.K., et al., *ApJ*, **788**, 111 (2014).

Authigenic clay mineral formation at Yellowknife Bay provides constraints on ancient martian P_{CO_2}

Thomas Bristow and David Blake – Exobiology Branch

Science Topic: Planetary Surfaces and Interiors

The widespread distribution of clay minerals in ancient martian terrains documented by OMEGA and CRISM provides a critical constraint on temporal changes in the abundance of planetary water. Following their discovery, the clays were proposed as evidence for warm and wet surficial conditions, largely restricted to the Noachian (older than 3.7 Ga). If clay mineral formation occurred rapidly enough in the surface environment then free exchange of dissolved volatiles with the martian atmosphere is implied. Based on this assumption and the absence of orbital detections of carbonates in clay-bearing deposits Chevrier et al., (2007) provided thermodynamic estimates of atmospheric P_{CO_2} in the Noachian. More recently, Ehlmann et al (2011) proposed that the bulk of clay minerals detected from orbit are a product of subsurface aqueous alteration, and thus clay minerals and associated phases are not expected to reflect the composition of the atmosphere.

The CheMin instrument, on Mars Science Laboratory, documented smectitic clay minerals (Fe-saponite) within carbonate-free lacustrine mudstones at Yellowknife Bay, Gale Crater. The clay minerals formed in place with magnetite via aqueous alteration of detrital olivine (Vaniman et al., 2014; Grotzinger et al., 2014; McLennan et al., 2014; Bristow et al., in press). Sedimentary structures and the kinetics of olivine alteration indicate the clay minerals formed before the mudstone was lithified, suggesting that the pore waters were influenced by the martian atmosphere (Grotzinger et al., 2014; Bristow et al., in press). Analogous clay minerals forming within cm's of the sediment-water interface on time scales of 100's to 1000's of years in crater lakes and depressions in the basaltic Western Plains district of Australia (Bristow et al., in prep.) support this idea.

The geochemical conditions required by Fe-saponite and magnetite authigenesis at Yellowknife Bay coupled with absence of definitive carbonate detections there place thermodynamic constraints on the levels of carbon dioxide in martian surficial environments at the time the Yellowknife Bay formation was deposited. The lower boundary of the carbonate stability field in this system depends on the proportion of Mg and Fe within saponite, with the transition at 0.048 bars for end-member Mg- saponite and 0.13 bars for end-member Fe(II) saponite (temperature 10°C). Moreover, if fluids contained Ca the carbonate stability field would extent to lower P_{CO_2} of between 0.01 and 0.001 bar (Chevrier et al., 2007; Bridges et al., in press). Ca-sulfates have been documented in veins and fractures that cross the Sheepbed mudstone (Vaniman et al., 2014), however, we cannot be sure this signifies Ca activity at the time of clay mineral and magnetite formation. Based on these considerations we obtain a conservative upper bound on P_{CO_2} of 0.13 bar in the martian atmosphere in the period post-dating the Noachian/Early Hesperian boundary (~3.7 Ga).

CRATER MORPHOLOGY IN THE PHOENIX LANDING ELLIPSE: INSIGHTS INTO NET EROSION AND ICE TABLE DEPTH

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Science Topic: Planetary Surfaces and Interiors

Icebreaker [1] is a Discovery class mission being developed for future flight opportunities to search for evidence of modern life on Mars. Under this mission concept, samples are acquired from the subsurface using a drilling system. To avoid the complexity of mating additional strings, the drill is single-string, limiting it to a total length of 1 m. The mission will be targeted to land in the same site as Phoenix, which has been found to be habitable [2], and where the presence of ice near the surface (4.6 cm deep at the Phoenix site) provides a source of H₂O that is thought to melt periodically at higher obliquities [3-5].

Because of the drill's limited vertical range, we seek to better understand the distribution of ice and the erosional history of the region. If the site has been a net depositional site and over a meter of sediment has been deposited since the last period of habitability (3-5 Mya), the Icebreaker sampling system will not be capable of accessing the sediments that were exposed to liquid water.

We performed an extensive morphological examination of the craters within the Phoenix landing ellipse. We searched HiRISE images (at 25 cm/pixel) for the freshest craters of varying sizes and estimated the net level of deposition since their formation by searching for ejecta blocks and measuring the sizes of these blocks. The age of these craters was estimated from the crater production rates constrained by previous studies [6; 7]. We identified over 2000 craters in the 4000 km² study region and catalogued them on the basis of crater size and degree of modification. Overall, we found that ejecta boulders are visible down to the resolution limit of HiRISE (~30 cm/pixel) for most craters larger than 200-300 m in diameter. Absence of ejecta boulders is typically associated to the most modified craters and craters smaller than about 200-300 meters (Fig. 1). According to [8], craters 250 meters and larger form roughly every 5 Myrs in a 4000 km² area. Hence, we infer that the region not has experienced a net deposition of 1 meter or more since the formation of these craters.

The absence of ejecta blocks in most craters smaller than 200-300 meters is particularly intriguing as it suggests impacts onto a layer of ice-cemented, friable, or unconsolidated soil approximately 20-30 m thick [9]. This layer likely overlies a basement of stronger material that is only exposed by larger impactors, and produces ejecta blocks in most larger craters (>300 m). Our inferred stratigraphy in his region is consistent with observations from SHARAD [10], which identifies a radar return at depths of 15-66 meters in the Phoenix landing ellipse. The presence of significant amounts of water ice, inferred from modeling and observations by GRS and the Phoenix lander [11], could explain the lack of ejecta boulders as due to sublimation of cementing ice post-impact.

References: [1] McKay et al. (2013) *Astrobiology*, 13(4) 334-353. [2] Stoker et al. (2010) *JGR* 115, E00E20. [3] Levrard et al. (2004) *Nature* **431**, 1072-1075. [4] Costard et al. (2002) 293, 110-113. [5] Richardson and Mischna (2005) *JGR* E3. [6] Malin et al. (2006) *Science* 314, 1573. [7] Daubar et al. (2013) *Icarus* 225, 506-516. [8] Hartmann (2005) *Icarus* 174, 294-320. [9] Mellosh (1996) *Impact Cratering*. [10] Putzig et al. (2014) *JGR* 119, 1936-1949. [11] Mellon et al. (2009) *JGR*, 119, 1936-1949.

Topographic Mapping of Paterae and Layered Plains on Io Using Photoclinometry

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Science topic: Planetary Surfaces and Interiors

No instrumentation specifically designed to measure the topography of a planetary surface has ever been deployed to the Galilean moon Io. We have generated regional-scale photoclinometry (PC) digital elevation models (DEMs) from Voyager and Galileo imagery of Io that resolve small-scale topographic features including paterae and layered plains. PC DEMs are primarily used for mapping local-scale topography, displaying significant topographic undulations over longer distances. Given the difficulty of applying the PC technique to Io due to the moon's anomalous and strongly varying surface albedo properties, we have experimented extensively with the relevant procedures in order to generate what we consider to be the most reliable DEMs.

We have tested the effects on PC-derived topography of varying the photometric function of the relevant scene, as well as cropping images to a fraction of their original coverage such that topography is generated only for selected landforms of interest, with minimal albedo variation across the scene. Results are compared with shadow length measurements in order to determine what combination of photometric function and cropping extent yields relief measurements that most closely match the shadow length values. We find that when a scene is cropped around a feature of interest such that the apparent brightness range is constrained by doing so, the relief of the feature in the resulting PC DEM is more comparable to that of the shadow measurement than if PC processing is done for the entire scene; however, if the feature of interest displays strong albedo variation across its expanse, then errors associated with the PC method may actually be aggravated by restricting mapping to its vicinity. The effect of changing the photometric function is not as influential as that of scene-cropping.

The DEMs have been used to gauge the depths of 23 paterae and the heights of 12 layered plains outcrops. The mean patera depth obtained from the PC measurements is 1.10 km ($\sigma = 0.37$ km), and the mean relief of the layered plains is 1.09 km ($\sigma = 0.44$ km), values that are very similar. There does not appear to be any correlation of either paterae or layered plains relief to either latitude or longitude. When considered in combination with the fact that there are many instances across Io where paterae appear to be closely associated with layered plains, we consider the very similar reliefs of the two landforms to support the existing hypothesis [Keszthelyi et al., 2004] that a mixed silicate-volatile layer covers much of the surface of Io. Intrusion of magma into the base of this surface layer would remobilize volatiles within it, destabilizing the layer sufficiently to promote collapse and form a patera, the depth of which is expected to be comparable to the thickness of the surface layer at that location. In addition, sapping of the volatile element in the same surface layer [Moore et al., 1996] would result in its erosion (in combination with gravity-driven slumping and other mass-wasting processes), forming the bounding scarps that define the edges of the layered plains units.

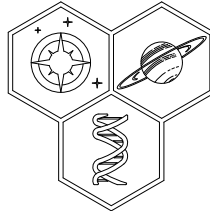
Title: Phase-Dependence of Physical Parameters of Near Earth Asteroids

Authors: Diane H. Wooden (ARC, SST), Sue Lederer (NASA JSC), Ellen Howell (Arecibo), Yan Fernandez (UCF), David Harker (UCSD/CASS), Erin Ryan (NPP, NASA GSFC), Amy Lovell (Agnes Scott), Charles (Chick) Woodward (UMN), and Lance Benner (JPL, Goldstone), and Vishnu Reddy (Planetary Science Institute).

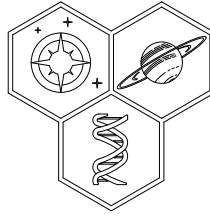
Science Topic: Planetary Surfaces and Interiors (Near Earth Asteroids)

A new effort at NASA Ames in the area of **Planetary Defense** has been funded by Lindley Johnson at HQ. As part of this effort, I (Diane Wooden, SST) am spearheading observational **Near Earth Asteroid** observational studies. Our team of co-investigators represents a multi-institutional, multi-disciplinary group of scientists with extensive experience in solar system observations.

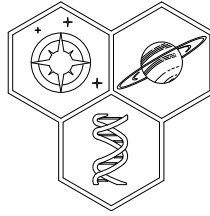
Here, our team presents details of our planned observation campaign of Near Earth Asteroids (NEAs) that will study the phase dependence of the reflectance and thermal emission spectra. During 05 March—19 April 2015, we will use UKIRT+Michelle's mid-IR spectroscopic and narrow band photometry capabilities, combined with UIST 1 – 2.5 micron spectra, or WFCAM photometry when NEAs are fainter than $V < 17$ mag, to characterize the albedos, diameters, and IR beaming parameters of select NEAs. NEAs are selected based on their visibility when UKIRT spectrometers will be available (UIST, Michelle), and based on being able to observe them through a wide range of phase angles (Sun-Target- Observer angles), ranging from less than about 10 degrees to greater than 45 degrees. The scattering properties and thermal properties of NEAs depend on the illumination and observing geometries, with the ideal observing conditions for thermal modeling being near zero degrees (the Sun at noon and the observer near noon). However, the orbits of NEAs often generate short observing windows at phase angles higher than 45 deg (whizzing by Earth). In fact, two of the three NEA families have Earth-crossing orbits, which means that they are brightest in the IR when they are interior to Earth's orbit. We have a program to observe 4 NEAs, two large and bright and 2 small and faint, with a range of phase angles with Michelle and UIST to investigate the effects of orbital phase angle and rotational longitude on deriving the thermal properties of NEA surfaces. Also, we will observe simultaneously the 0.75-2.5 micron spectra with IRTF+SpeX and with UKIRT+Michelle to nail down the albedos and to test the sensitivity of such measurements to those done just on UKIRT with subsequent night observations of mid- and far-red—near-IR. Our observations will impact our understanding of the fidelity of more common single epoch mid-IR and near-IR measurements to obtain albedo, size and IR beaming parameters (the outcomes of thermal models).



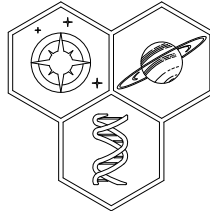
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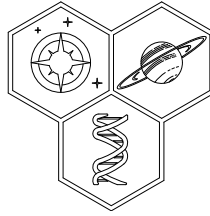
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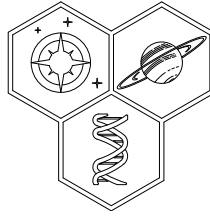
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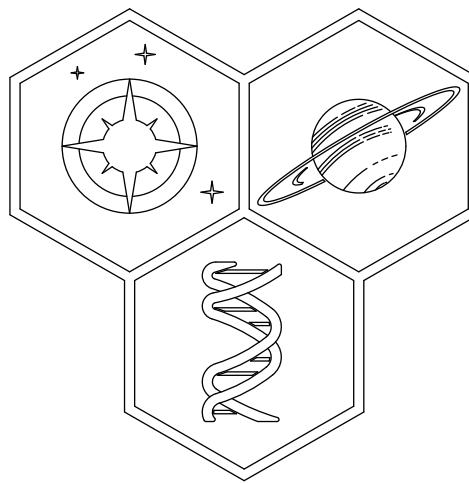
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2015 NASA Ames Space Science & Astrobiology Jamboree Notes



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To extend life to there,
To find life beyond.



NASA Mission: To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
.....as only NASA can.

